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TREATMENT AND DISPOSAL OF HAZARDOUS
WASTES IN THE EAST CENTRAL FLORIDA REGION

BY

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B.A., Colgate University, 1976
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RESEARCH REPORT

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ABSTRACT

TREATMENT AND DISPOSAL OF HAZARDOUS WASTES IN THE EAST CENTRAL FLORIDA REGION

by

Tracey Bell

Although the East Central Florida area is not heavily industrialized, its dependence on groundwater resources makes it especially vulnerable to contamination by poor waste disposal practices. The East Central Florida area was studied to discover the nature and disposal of hazardous wastes generated. It was found that a large portion of hazardous wastes in the region were from very small industries, distributors, and even consumers. Three of the most toxic and/or voluminous waste problems in the area--metal plating wastes, pesticide wastes, and hospital wastes--were studied to determine available alternatives for disposal and their costs.

ACKNOWLEDGEMENTS

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I INTRODUCTION

The problem of hazardous waste generation in the Central Florida area seems at first to be relatively unimportant. Few industries are present, and those that exist do not produce large amounts of hazardous wastes. There are, however, many small manufacturers, distributors and consumers who must dispose of small amounts of hazardous material. Some of the manufacturers and distributors have their own waste treatment plants, but even these sometimes have sludges or incinerator wastes to be landfilled, land spread, or buried. Consumers and companies with few wastes would not have any treatment facilities at all. Since there is no chemical landfill in the area, most of the wastes which must be landfilled are placed in a regular sanitary landfill. (Untreated consumer wastes could be discharged onto the ground, into a waterway, or discharged into municipal sewage treatment plants.)

A six county area, consisting of Orange, Seminole, Brevard, Volusia, Osceola and Lake counties, was studied to discover what hazardous wastes were generated and how they were disposed of. The major industries in the area were food processing, aerospace, electrical equipment, and power generating. Other sources of hazardous wastes included metal plating job shops, battery manufacturers and hospitals. The agriculture industry as a whole must be considered to be a hazardous waste generator, also, even though the amount of

toxic material disposed of by any given individual may be quite small.

The rock strata underlying the study area are limestone. This rock is porous and easily dissolved by the slightly acidic rainwater, so a natural, interconnecting aquifer has been formed, from which 99% of the water used in the study area is taken (Florida Department of Natural Resources 1972). The interconnection of the aquifer over the entire area makes it particularly vulnerable to contamination. Hazardous waste planning and safe disposal methods are therefore a necessity for the study area.

"Hazardous wastes" have been defined as "wastes that create a present or potential hazard to human health or living organisms" (Report to Congress 1974). This hazard may be due to the wastes' lethality, to its persistence in the environment, to its tendency to be biologically concentrated, or to its cumulative detrimental effects.

Hazardous wastes can also be divided into five general categories: flammable, toxic, explosive, biological and radiological (Report to Congress 1974). Flammable wastes include contaminated organic solvents, oils, pesticides and other chemicals. Toxic wastes (which compose a very large proportion of hazardous wastes) include toxic metal containing wastes, synthetic organics (such as PCB's and pesticides), and corrosive wastes. Explosive wastes consist of obsolete ordnances, wastes from explosives manufacturing, and fertilizers such as ammonium nitrate. Biological wastes are hospital

and laboratory wastes (Report to Congress 1974).

(It is estimated that 10% of industrial wastes are hazardous. The majority of these hazardous wastes are generated by 14 industries, including battery manufacturers, plating shops, electronics manufacturers, pesticide producers and consumers, and pharmaceutical companies. By 1983 wastes from these industries nationally are projected to have increased (from their 1973 values) by rates ranging from 30% for petroleum refining to 2000% for the battery industry. A large percentage of this growth in waste production, however, will be from increased air-and-water-pollution control requirements (Kovalick 1977).)

This paper first discusses the basic methods for treatment and disposal of hazardous wastes, highlighting the methods that are presently used in the study region. The particular problems of the area are then discussed, followed by an economic analysis of disposal methods for certain hazardous wastes in the East Central Florida Region (ECFR).

II TREATMENT AND DISPOSAL OF HAZARDOUS WASTES

Background

Large amounts of hazardous industrial wastes are generated each year. Most of these wastes are eventually disposed of on land, especially since air and water pollution regulations have become more restrictive (Kovalic 1977). Wastes can be treated physically, chemically, or biologically. Treatment either degrades and neutralizes the toxic elements or concentrates these elements for disposal. The concentrated wastes, or waste streams not amenable to treatment can be incinerated, placed in a landfill, buried in a vault, or dumped in the ocean. The above four processes are termed "ultimate disposal". A newly emerging alternative and correlary to ultimate disposal and treatment is waste/energy recovery.

The treatment or disposal (T/D) method(s) chosen for a particular waste stream depend on the waste characteristics, waste source, and the purity and disposal method desired for the final effluent. Waste characteristics include whether the waste is in liquid, solid or gaseous form, what chemical components it contains, what hazards it presents, and what concentration and rate of generation it has. Possible sources of hazardous wastes include the manufacturer of products which have hazardous byproducts; the transporter of the product, who might accidentally discharge it into the

environment as a hazardous waste; the user of the product, who might have empty containers, unused product, or dilute contaminated rinsewater to dispose of; and the final waste disposer, who might, by improper disposal, release the hazardous materials to the surrounding land, air, or water.

For many industrial processes, regulations have been passed setting an upper limit to the concentration of toxic substances in the effluent. It is necessary for these industries to use a T/D system that will attain the required standards. If chemical recovery from a waste is desired, a process that concentrates the chemical in question to a recoverable form is required.

Some of the common T/D processes are described in the following section. Applications of each method have been indicated.

Waste Treatment

A complete list of treatment processes, ultimate disposal processes, and energy recovery processes is shown in Table 1. Waste treatment consists of physical, chemical, and biological processes.

Physical Treatment

Physical treatment of a waste involves separating and concentrating the hazardous portion of a waste for further treatment or ultimate disposal. Waste concentration reduces the cost of later processing operations, and makes chemical recovery more feasible. Sometimes, however, concentration can make a waste excessively dangerous to handle.

TABLE I
T/O METHODS

PHYSICAL TREATMENT	CHEMICAL TREATMENT	BIOLOGICAL TREATMENT	ULTIMATE DISPOSAL
Adsorption	Neutralization	Activated Sludge	Landfill
Reverse Osmosis	Ion Exchange	Trickling Filter	Land Burial
Sedimentation	Chemical	Land Spreading	Deep-well Injection
Electrodialysis	Oxidation/ Reduction		Ocean Dumping
			Dilution and Dispersal

1 Adsorption

Adsorption is the process of passing a waste stream over an adsorbent, to which certain elements of the waste stream will adhere. A common adsorbent is activated carbon since it is inexpensive and will adsorb a wide variety of contaminants.

Carbon adsorption is less effective at high concentrations, high pH, and high temperatures. For this reason, it is used primarily to polish an effluent which has already been treated by other methods, or on very dilute effluents. The carbon can be regenerated or discarded and replaced. In either case, a concentrated sludge is produced which can either be processed for chemical recovery or disposed of (Huang and Wu 1975).

Carbon adsorption has been used to treat chromium and cyanide plating rinse waters (Scaramelli 1976). In addition, it has been shown to remove low concentrations of PCB's from aqueous solutions (Tosine 1976).

2 Reverse Osmosis

In regular osmosis, water (solvent) flows from a region of low concentration of salt to a region of high concentration of salt due to osmotic pressure. The flow takes place through a semi-permeable membrane which allows solvent through, but not solute. The flow continues until the activities of solvent on both sides of the membrane are equal.

To reverse osmosis, pressure is applied to the side of the membrane with the least solvent concentration, which overcomes os-

motric pressure and causes the solvent to flow in the direction of higher concentration of solvent. This leaves a concentrated solute compartment (Ahlgren 1976).

Many different substances can be removed by this process, from heavy metals to bacteria and viruses. The pH range of the waste to be treated must be between 3 and 8, and concentration of the chemical to be removed should not exceed 4-10%. The membranes are highly specific for particular species (Ottinger 1973). The concentrated solute from the process could be recycled or further treated.

Reverse osmosis is still in an experimental stage and is therefore still quite expensive. The process has the potential for being the lowest cost operation for removing toxins from water because it operates more closely than any other process to thermodynamically ideal conditions (Ahlgren 1976).

Sedimentation and Precipitation

Sedimentation usually involves the addition of a coagulant or precipitant such as lime, ferric chloride or sulfate, or alum to a waste. The least expensive precipitant is lime, especially when added as part of neutralization, since heavy metals precipitate at a pH of 9 (Maruyuma 1975). The waste is then routed to a settling pond, where the coagulated particles are allowed to settle. Efficiency of the sedimentation process depends on the settling tank temperature, the specific gravity of the suspended solids, the concentration of particles and other factors (Lash 1975).

Disposal of the sludge generated by this process can be a problem because of its high water content and high concentration of toxic wastes. In addition, further treatment of the effluent is usually necessary.

Electrodialysis

A salt dissolves in water to produce positive cations and negative anions. In the presence of an electrical field, the cations are drawn toward the negative cathode and the anions are drawn to the positive anode. An electrodialysis unit is composed of layers of membranes, alternately permeable only to cations and only to anions. In this layering, the solution between one pair of membranes becomes rich in salt, and the solution between the next pair becomes depleted. Up to sixty membranes are stacked together and the liquid is run through the same stack five or six times, or through five or six consecutive stacks in order to obtain 95% efficiency (Leitz 1976).

Electrodialysis works over the complete range of pH and is not as specific as reverse osmosis. Organic solids in the waste to be treated must first be removed (i.e., by treatment with activated carbon). The treatment is obviously unusable for removal of nonionized contaminants. In addition, concentrations higher than thousands of ppms will probably not be reduced to an acceptable level (Ottinger 1973).

Biological Treatment

Biological treatment processes are primarily used to reduce organic toxic waste streams. They usually depend on the ability of microorganisms to biodegrade waste material to non-toxic products such as CO_2 and H_2O .

Activated Sludge

In the activated sludge process, wastes are mixed with microorganisms recycled from the system. The micro-organisms feed on the organic contents of the wastewater, decomposing it. This activity creates flocculent suspensions. The incoming wastes are mixed rapidly with the recycled sludge and oxygen is added by mechanical aerators. The settled sludge is reclaimed from the purified effluent and recycled back to the activated sludge tanks.

Pre-treatment of wastes by neutralization to the 5-9 pH range and removal of materials toxic to the sludge are necessary before activated sludge treatment is begun. The process will acceptably remove many organic wastes, including acetic acid, alcohols, pesticides and phenolics with an efficiency of 90-95%. Some, but not all, heavy metals are removed with efficiencies ranging from 30% (Zn) to 90% (Pb). Since the system is sensitive to surges in waste loads, it is usually used in combination with other processes, such as the trickling filter.

Trickling Filter

A trickling filter is a vertical filter of rocks or some syn-

thetic materials through which wastes are allowed to run slowly. Bacteria grows on the rocks, and organic material is removed from the wastes by this biological slime.

Trickling filters remove most organics, including ammonia, formaldehyde and cyanides. Metals are also partially removed, with an efficiency of 20-40%, however these metals will be concentrated in the secondary sedimentation tank following the filter and will have to be disposed of. Trickling filters are less efficient than activated sludge process. Thus they are often used as the first step in a series of treatment steps (Ottinger 1973).

Land Spreading

In one form of land spreading, wastes are sprayed on a suitable field until they begin to pond. The field is allowed to dry until cracks appear, then is rototilled to a depth of six inches. The tilling aerates the soil and assists in mixing of contaminants.

Landspreading is a viable alternative if low cost real estate is available with the proper soil types. To preclude percolation of toxins to the water table, the spray field should be located so that escape of toxins to surface or groundwater is impossible. A climate in which the annual evaporation exceeds the annual rainfall is preferable. The limit of usefulness of a spray field is determined by the capacity of soils to adsorb the wastes. Once this capacity has been exceeded, the metals are free to percolate to the water table. A spray field should therefore be carefully monitored with monitoring wells (Ganze 1977).

Chemical Treatment

Chemical treatment changes a hazardous waste to a less corrosive or less toxic waste. Included in this category are neutralization, ion exchange, and chemical oxidation and/or reduction.

Neutralization

Neutralization is the process of adjusting the pH of highly acid or alkaline wastes to near neutrality. In a waste that is only toxic because of acidity or alkalinity this is sufficient treatment, but more usually neutralization is a preliminary to other treatments or ultimate disposal. An alkaline waste can be treated using sulfuric or hydrochloric acid. An acid can be neutralized using sodium or calcium hydroxide, limestone or hydrated lime. Sodium hydroxide is quite expensive, however it is widely used due to convenience and ready availability (Lash and Kominek 1975). Limestone and hydrated lime are inexpensive and effective with hydrochloric acid wastes, but form CaSO_4 precipitate when used to neutralize sulfuric acid.

Ion Exchange

Ion exchange is a process of exchanging ions reversibly between a liquid and a solid phase. Either a cation exchanging resin, an anion exchanging resin, or a resin that exchanges both cations and anions may be used, depending upon the substances to be removed. Like activated carbon, the resin may be regenerated and have the adsorbed materials removed (Ahlgren 1976).

Ion exchange will remove and concentrate all ionic species

listed as toxic by the EPA. Since the resins are quite specific, ion exchange is usually used in combination with other methods, with the ion exchange removing certain substances. The process is most effective and economical for use with a relatively low concentration of the toxin in question. The regeneration liquid may be either disposed to a landfill or may be processed to have contaminants recovered and recycled (Ottinger 1973).

Chemical Oxidation/Reduction

Chemical oxidation/reduction can be used to treat many hazardous materials. Cyanides can be oxidized with chlorine gas or sodium hypochlorite at a pH of 10. Hexavalent chromium can be reduced using sodium metabisulfite ($\text{Na}_2\text{S}_2\text{O}_5$) at a pH of 2. Many pesticides can be oxidized using chlorine, chloride dioxide, potassium permanganate, ozone, or peroxide. In oxidation of pesticides, it is necessary to first ascertain whether the product will be more toxic than the original pesticide. (Parathion, for instance, is oxidized by chlorine and ozone to the more toxic paraoxone) (Atkins 1972). Degradation by mixing with NaOH is used for organophosphorous pesticides (Ottinger 1973).

Ultimate Disposal

The term "ultimate disposal" implies disposal of waste material on, or in, the land or in the ocean. The techniques that fall into this category are as follows: landfilling, land-burial, deep-well injection, ocean dumping and dilution/dispersal.

Dilution and Dispersal

One of the ways of dealing with hazardous wastes is to reduce their concentration by dilution to a point deemed harmless and then to disperse them to the air or water. If the waste in question is rapidly biodegradable and relatively non-toxic then dilution and dispersal may be applicable. If the waste is essentially non-biodegradable (for instance, heavy metals) or if it is highly toxic, dilution and dispersal is a very dangerous method, since eventually the wastes will accumulate to a hazardous concentration.

Landfilling

There are three gradations of waste disposal by landfilling: (1) open dumping (2) sanitary landfilling (3) chemical, or secured landfilling.

Open dumping consists of transporting wastes to the dumping site and leaving them there. This has the advantage of low cost, but multiple disadvantages. Open dumps encourage insects and rodents, serve as a reservoir for disease, and produce odors. In addition, if hazardous wastes are dumped, rainwater can percolate through them, forming a hazardous leachate which eventually reaches the ground water. If the wastes are dry, or if they volatilize, the toxic materials can be carried by the wind.

Sanitary landfilling consists of mixing the wastes with soil, then firmly compacting them in layers, with a final cover of soil. The wastes are decomposed by soil bacteria. A sanitary landfill is

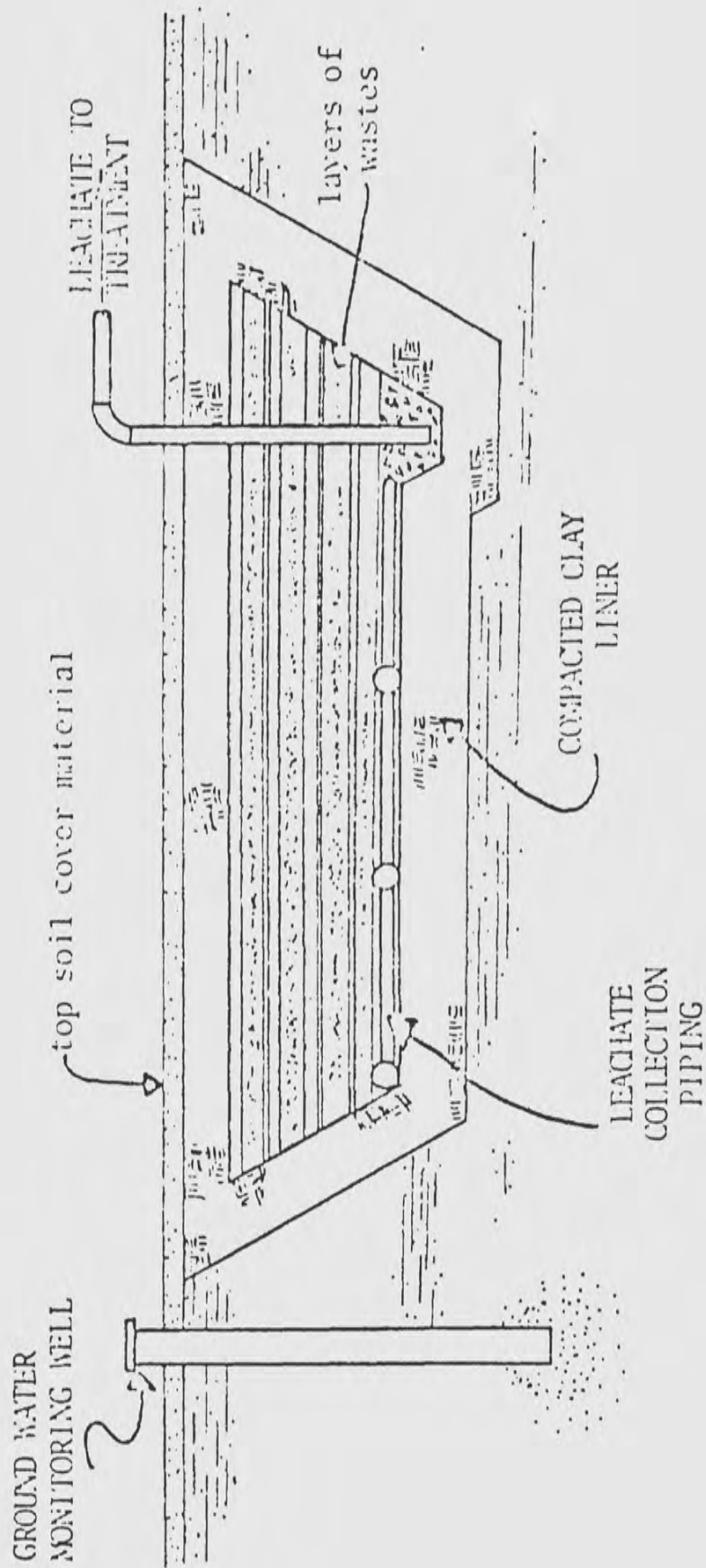


Fig. 1. Schematic diagram of a chemical landfill

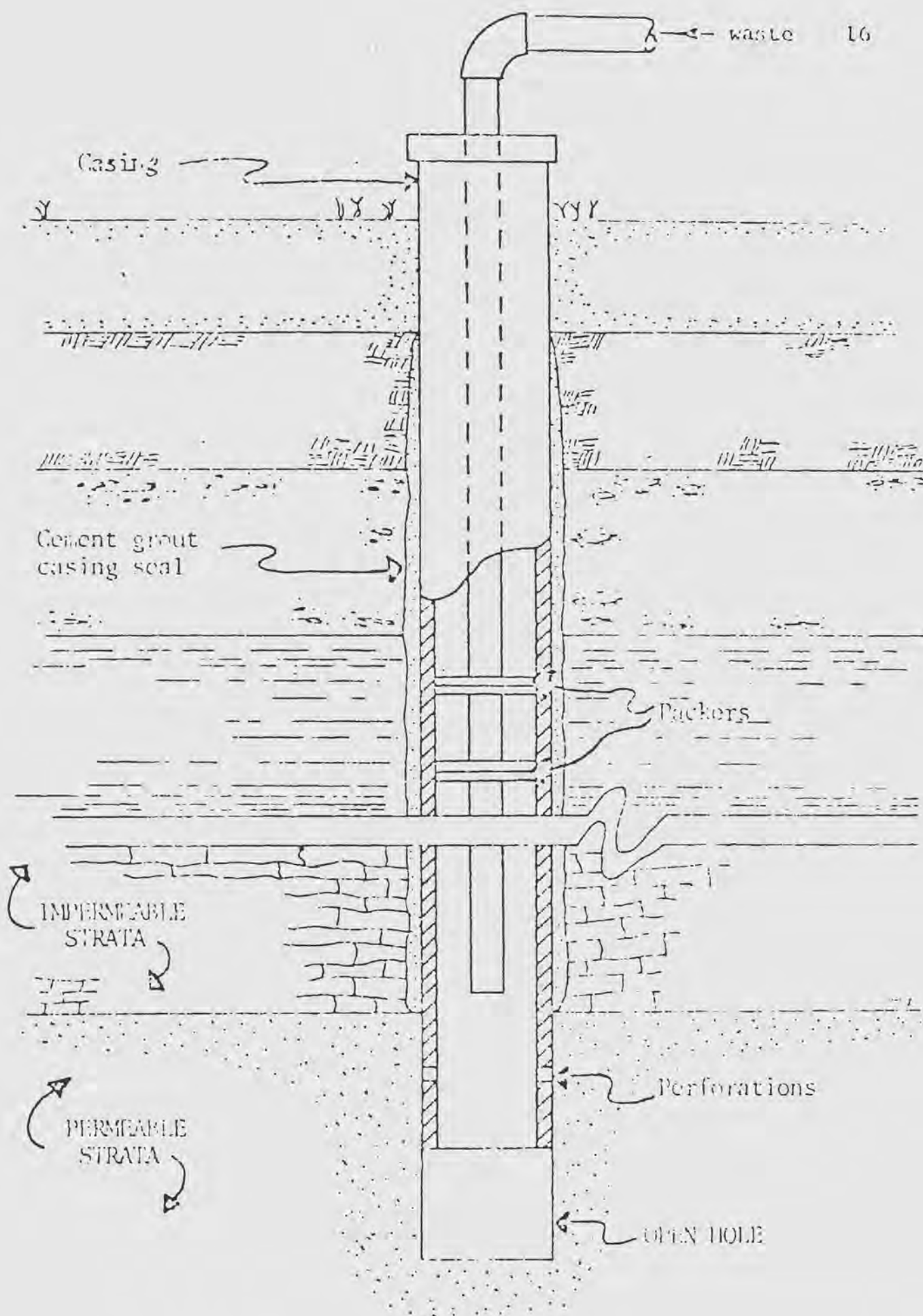


Fig. 2. Schematic diagram of deep well injection system

planned with the bottom of the landfill several feet above the water table and the completed site is mounded in the middle to allow water to drain away from the wastes instead of through them.

Sanitary landfilling is the method of disposal most often used for solid wastes (Hazardous Wastes Research Symposium 1976). One disadvantage is potential pollution of groundwater from toxic wastes. If specific hazardous wastes are inherently non-leachable or if they have been treated to make them so, then a sanitary landfill is a possible alternative for their disposal. If wastes are leachable, or if they have the possibility of volatilization, they should not be disposed of in a sanitary landfill, but should be placed in a chemical landfill.

One of the most important requirements for a chemical landfill is a secure site. The California Class I (hazardous waste) landfill site criteria state that geological barriers to the horizontal or vertical mixing of waste liquids or gases with usable groundwater must exist; that the site must not be subject to wash-out; that the leachate should be confined within the site; that sites should not be located over active faulting zones; and that the landfill should not be located in an area of extensive population (Fields and Lindsey 1975).

In addition to a safe site, other methods are used to secure the wastes against polluting the environment. Wastes are sorted and separated to prevent mixture of components that might unite to form hazardous gases or an explosion. Percolation barriers are placed on

top of the landfill to prevent entrance of water (See figure 1). A leachate drainage and collection system is installed and hazardous leachate is collected and treated. A system of wells to monitor adjacent groundwater is set up (Fields and Lindsey 1975).

Chemical landfills, unless geological barriers to water migration are perfect, are usually lined to prevent escape of contaminated fluid. Such liners can be compact native fine-grained soils, clays, asphalts, portland cements, soil sealants such as penetrating latex or lime, sprayable liquid rubbers and synthetic polymeric membranes (Hazardous Wastes Research Symposium 1976). Which liner is used (or which combination of liners) depends on the type of waste it will be used with, the allowable level of permeability, the lifetime required and whether the liner will be exposed to sunlight and weather (Hazardous Wastes Research Symposium 1976). Wastes are often treated by chemical neutralization, encapsulation, or other processes to reduce their toxicity before placing them in the landfill.

The chemical landfill has the advantage of safely disposing of hazardous wastes at a still relatively moderate cost. For some hazardous wastes, no technology has been discovered to create an alternative to chemical landfilling. Disadvantages are the ever present danger of leakage and the resultant requirement of monitoring the site for long years after it is completed. There may be public resistance to having a landfill nearby and to the usage of land which may become valuable, but which will be unavailable for re-use for many years.

Land Burial

Land Burial is essentially the idea of a chemical landfill carried to the point where the waste is completely surrounded by a vault. Material is solidified, then placed in a concrete or steel trench and covered with concrete, with a top layer of soil. The area around the trench is monitored to detect leakage. The same site selection criteria used in selecting a place for a chemical landfill is used in finding a site for land burial (Ottinger 1973).

Land burial is essentially storage--nothing is done to the wastes and little oxygen can reach them to help in decomposition. The wastes simply remain, occupying space and posing the threat of leakage and contamination, until technology is discovered to deal with them.

Deep Well Injection

There are two types of deep well injection. The first uses relatively shallow wells ($\approx 300'$ - $2000'$) and consists of injection of treated municipal wastewaters or other non-toxic fluids into the ground fairly near the groundwater table. This method has been used to recharge aquifers, and to prevent saltwater infiltration along the coasts. The second type consists of deep ($3000'$ - $12,000'$) injection of toxic wastes (Forrestal 1975).

For safe toxic waste injection, certain requirements must be met. In the site picked for the deep well, the water table must be underlain by impermeable rock (clay, shale) which must in turn have

beneath it a permeable (sandstone, dolomite, limestone) stratum to use as the receptor of the wastes.

A well is drilled to the permeable rock. Two or more casings are used to prevent leakage into the fresh water aquifer and cement is used to seal the annular space. Injection tubing is inserted, with packers to hold it in place, and the well is perforated at the appropriate stratum (See figure 2). The space between the tubing and the casing can be filled with an inert fluid and a pressure gage can be installed. This allows the operator to tell, by a change in pressure, whether leakage from the pipe is occurring (Ottinger 1973).

The waste must be treated before injection to prevent clogging of the pores of the receiving aquifer. The waste should be filtered, using a diatomaceous earth filter. If it has a high BOD, sterilization with a bactericide to prevent growth of microorganisms is necessary. If oils are present in the wastes they must be removed to prevent fouling of the injection zone (Report to Congress 1977).

To increase permeability, acid is sometimes injected into a limestone stratum. If a reaction between the waste and the rock or native water that would cause a decrease in permeability is likely to occur, a buffer solution is injected before the waste. Permeability may be increased by hydraulic or explosive fracturing, however, this may cause vertical fracturing, which would allow mixing between wastes and groundwater (Ottinger 1973).

The advantages of deep well injection are that the cost is low, and that less treatment is necessary for deep well injection

than for a landfill.

Many disadvantages to deep well injection have been found. The low cost of the method is partly offset by the cost of monitoring which should include, at a minimum, pressure gages at the well to detect leakage and fresh water aquifer monitoring wells. Often, geological sites are poorly chosen and monitoring is ignored.

The groundwater can be contaminated in many ways. Wastes can be directly emplaced into a freshwater aquifer. The well casing can be fractured by too high an injection rate (injection rates usually range from 2 gpm to 600 gpm, with over half of existent wells having rates below 100gpm). If the casing is improperly installed, upward migration along it can occur. Leakage can occur through inadequate confining beds, or through abandoned deep wells (for instance petroleum exploration wells) or through hydraulic fractures. Saline water that is displaced by injection may move into a potable aquifer (Report to Congress 1977). At least one author has found a correlation between deep well injection and earthquakes (Forrestal 1975).

The EPA report to congress on waste disposal practices finds that if deep wells are properly placed and monitored they can pose a minimal threat to groundwater (Report to Congress 1977). Ottinger, however, does not recommend use of deep wells for hazardous wastes because of the danger of groundwater contamination and because of the lack of control over the wastes once they are injected (1973).

Since the ECFR is extremely dependent on its groundwater resources, deep well injection would seem very hazardous for the

study area.

Ocean Dumping

Ocean dumping commonly falls into one of three classes. The largest portion of wastes are disposed as bulk liquid or slurry from barges. The wastes are disposed of at a distance of from 10-125 miles from shore while the barge maintains a speed of from 3 to 6 knots. Speed of the barge and rate of release of the waste are governed by the type of waste and its toxicity. Rates of release are usually 4-20 tons/minute (Ottinger 1973).

Wastes are also disposed of in individual 55 gallon drums. The drums may either be perforated so that the contents are diluted by ocean waters, or weighted so that the water is used as a burial medium. The drums are released up to 300 miles from shore. They should weigh at least 550 lbs, to prevent them from floating, or be encased in concrete block (Ottinger 1973).

The primary advantage of ocean dumping is its low cost--lowest of all the ultimate disposal methods discussed here. Some wastes are judged to be less harmful to the environment when dumped in the ocean than when disposed of on land. Ottinger (1973) states that the effects of some wastes (those that do not contain elements that are concentratable by marine life) are limited to short time periods and the immediate area of disposal and that wastes are diluted completely within twelve hours. He recommends that before ocean disposal of wastes occurs tests be made to detect whether the wastes react with ocean waters to form toxic products.

The disadvantages of ocean dumping center primarily on the danger of concentration by marine organisms. The complex barriers to biological uptake that have been built up in terrestrial fauna to not exist in the ocean. Thus, shellfish, for example, concentrate hazardous material at a rate unequalled on land (Ember 1975).

Degradation takes place very slowly in the ocean, and a complex such as an organochlorine pesticide, which would be degraded by soil bacteria on land, is undegraded in the ocean. Research has suggested that there is no freeliving population of microorganisms in deep water to carry out degradation (Wirsén and Jannasch 1976).

Incineration

Incineration is a highly developed technology which can easily be transferred to hazardous waste disposal. The process reduces the volume of materials and if the toxicity is due to the structure of the material, the process also serves as a detoxification process. Incineration is broadly applicable to organics and can be adapted to handle large volumes of materials. Unlike landfill disposal, incineration requires only a small land area (Scurlock 1975).

Incineration is more costly than landfill, and the equipment involved is more complicated to operate. If the material to be burned is toxic due to elements it contains (such as heavy metals), these elements will not be destroyed, but will be vaporized, or remain in the ash, which must still be disposed of. Any burning of

hazardous wastes poses a problem of potential air pollution, which must be prevented by use of effluent purification devices ("Sludge Incineration" 1970).

How effective combustion is, and whether the process, by incomplete combustion, simply creates more pollutants, is a function of several variables. The first variable is the combustibility of the waste to be burned. If there are very few combustible elements present, excess fuel must be added. An adequate dwell time must be allowed. The temperature is usually from 1800°F to 2000°F and is partially controlled by the amount of excess oxygen present.

Another variable is turbulence--the amount of mixing taking place. This can be controlled by grates, mechanical or hand pokers, baffles, or aerodynamic methods. Some incinerators induce turbulence as part of the burning process (for instance, the rotary kiln and fluidized bed incinerators) (Ottinger 1973).

The size and type of incinerator to be chosen depends on the weight and volume of the wastes. In some cases, sheer physical bulk of the waste is a factor. Considerations such as whether batch or continuous production is needed, the collection and handling methods necessary for the waste, the feeding speed and method desired, the daily firing period and whether heat recovery is necessary are fundamental in choosing an incinerator (Dunn, 1975).

Some wastes are highly corrosive, most particularly those containing halogens. To incinerate these, it is necessary to have special, non-corrosive refractories. If a waste is highly toxic,

its handlers will need to follow special procedures, such as the use of respirators, protective clothes and gloves. If inorganic salts are present, a high energy venturi scrubber may have to be installed to prevent their escape to the atmosphere. If halogen ions are released in the fumes, excess H_2 can be injected into the gas stream, and the resultant acid removed by scrubbing with a caustic solution. A scrubber may also be necessary if SO_x is present in the gas (Dunn 1975).

At high ($>2000^{\circ}F$) temperatures in incinerators, NO_x is formed. This gas is extremely difficult and expensive to remove from the gas stream, so it is generally left in the gas and released to the atmosphere. Incinerators which use low temperatures with much excess air are favored over high temperature incinerators because they prevent the formation of NO_x (Dunn 1975)

Pyrolysis

Pyrolysis involves exposure of wastes to high temperature in an airless environment (to prevent combustion). The gaseous products are usually steam, CO , CO_2 , H_2 and CH_4 . Liquid products are various organics, usually including methanol, ethanol, acids and tars. The solid is usually charcoal, mixed with the inorganic, nonvolatile components of the waste.

The advantage of pyrolysis is its potential for recovery of economic value in waste processing. The gases could be processed for heat recovery, the liquids could be burned for fuel and the solids, providing they did not contain actively hazardous inorganic

components, could also be burned for fuel. Pyrolysis is still in the experimental stage (Scurlock 1975).

Waste/Energy Recovery

Waste/energy recovery occurs primarily when energy or resources are scarce or expensive. Most of the physical treatment methods discussed above are, in part, recycling processes, since they separate and concentrate a certain group of chemicals, which can be reused or sold.

Waste can also be used in its raw state, for example the proposed project to revegetate strip mines in Philadelphia with industrial sludge (Ember 1975). The sludge contains heavy metals, which can be concentrated in plants, however, the vegetation will be ornamental only and not used as food for animals or humans. This points out another consideration in recycling: a recovery system that uses raw hazardous wastes will have to take into account the qualities which make the waste hazardous.

A refinement of waste recycling is the waste clearinghouse. Typically, a waste clearinghouse would exist to put a waste producer in touch with a potential waste user. The composition of a particular company's waste stream remains confidential, and specific negotiations would be the responsibility of the industries involved.

Prototype clearinghouses in St. Louis and Europe report success and state that the clearinghouse gives waste users an economic incentive to discover uses for the wastes. The producer would have an incentive to adapt the industrial process to produce a usable

waste stream (Harness 1977). A study in Philadelphia shows, however, that only 9% of wastes in that city have exchange potential, and of those only twenty percent would actually be exchangeable due to economic and practical limitations (Ricci 1976).

The advantages of waste/energy recovery as a whole are obvious. Waste does not have to be disposed of through ultimate disposal and non-renewable resources are not wasted. Sometimes recovery and recycling are the most economical alternatives for disposal.

Disadvantages are that the recovery process is still largely experimental and is prone to expensive failures or inefficient operations. Markets for recovered material are sometimes unstable and if a contract for receiving the material is not renewed, dumping costs added to recycling costs would make the waste disposal extremely expensive (Wingerter 1976).

III SOME SPECIFIC HAZARDOUS WASTES IN THE ECFR AND T/D ALTERNATIVES

Three wastes in the ECFR of most interest--pesticides, hospital wastes, and plating wastes--were studied in more detail. Alternatives to the methods presently used to dispose of these wastes were investigated. These processes are discussed below. The economics of the alternatives are reviewed in chapter IV.

Plating Wastes

Plating wastes account for a large portion of the toxic metal wastes in the ECFR. Captive shops are incorporated in the large electronics and aerospace industries. In addition, there are a number of small job shops in the area. Both of these categories of plating shops are affected by the 1972 Federal Water Pollution Control Act, which requires that the Best Practical Technology (BPT) be employed to reduce effluent by 1977, and the Best Available Technology (BAT) be in use by 1983. In the case of plating wastes, BPT includes destruction of oxidizable cyanides, reduction or removal of hexavalent chromium and removal of all but small amounts of metals. BPT effluent limitations are contained in Table 2.

At present, the larger industries re-use the plating wastes within the plant or send them to a recycling company. The smaller companies chemically oxidize cyanides. Cr^{+6} is reduced to Cr^{+3} , (See figure 3), which is then precipitated by increasing the pH

TABLE 2

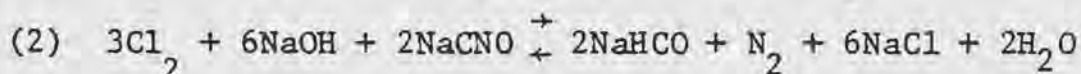
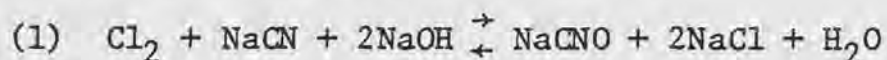
BPT EFFLUENT STANDARDS FOR METAL PLATERS

ELEMENT	1 DAY MAX MG/1	30 DAY AVG MG/1
FIRMS WITH CAPACITY 10,000 GPD		
CN ⁻ A	2	0.8
CR ⁺⁶	0.25	0.09
FIRMS WITH CAPACITY 10,000 GPD		
CN ⁻ A	0.2	0.08
CN ⁻ TOTAL	0.64	0.24
CR ⁺⁶	0.25	0.09
CR TOTAL	4.2	1.6
TOTAL METALS	7.5	3.6

SOURCE: "Effluent Standards for Metal Platers," Federal Register 43, no. 170 (10 October, 1976):6570.

(McManemy 1978). Some alternatives to chemical reduction and oxidation include electrochemical oxidation and reduction, carbon adsorption, reverse osmosis and ion exchange.

Chemical oxidation of CN^- is accomplished using chlorine gas according to the following two reactions:



In a continual flow process, (See Fig. 4) the cyanides are oxidized to cyanates (Equation 1) in one tank, pH adjusted to 9.5-10, then further oxidized in succeeding tanks at pH 8. Each tank is agitated continuously. Batch treatment is also possible (Costle 1978).

Chemical reduction of Cr^{+6} takes place with the addition of sodium metabisulfite ($\text{Na}_2\text{S}_2\text{O}_5$) to a chromium containing waste that has first been pH adjusted to 2-3 with sulfuric acid. The chromium is reduced to the $+3$ state as $\text{Cr}_2(\text{SO}_4)_3$ which precipitates. Chromium reduction leaves a low pH effluent which must be neutralized, usually with NaOH (See Fig. 5). The sludge which is formed when $\text{Cr}_2(\text{SO}_4)_3$ precipitates must be disposed of. Chemical reduction of chromium may be either continuous or batchwise (Battelle Laboratories 1971A).

Both CN^- oxidation and Cr^{+6} reduction can be designed to give any degree of effluent purity desired. They are both proven technology. The pH must be carefully controlled for effective chemical action in both cases. For CN^- oxidation, storage and use of chlorine gas represents a possible hazard (Battelle Laboratories 1971B).

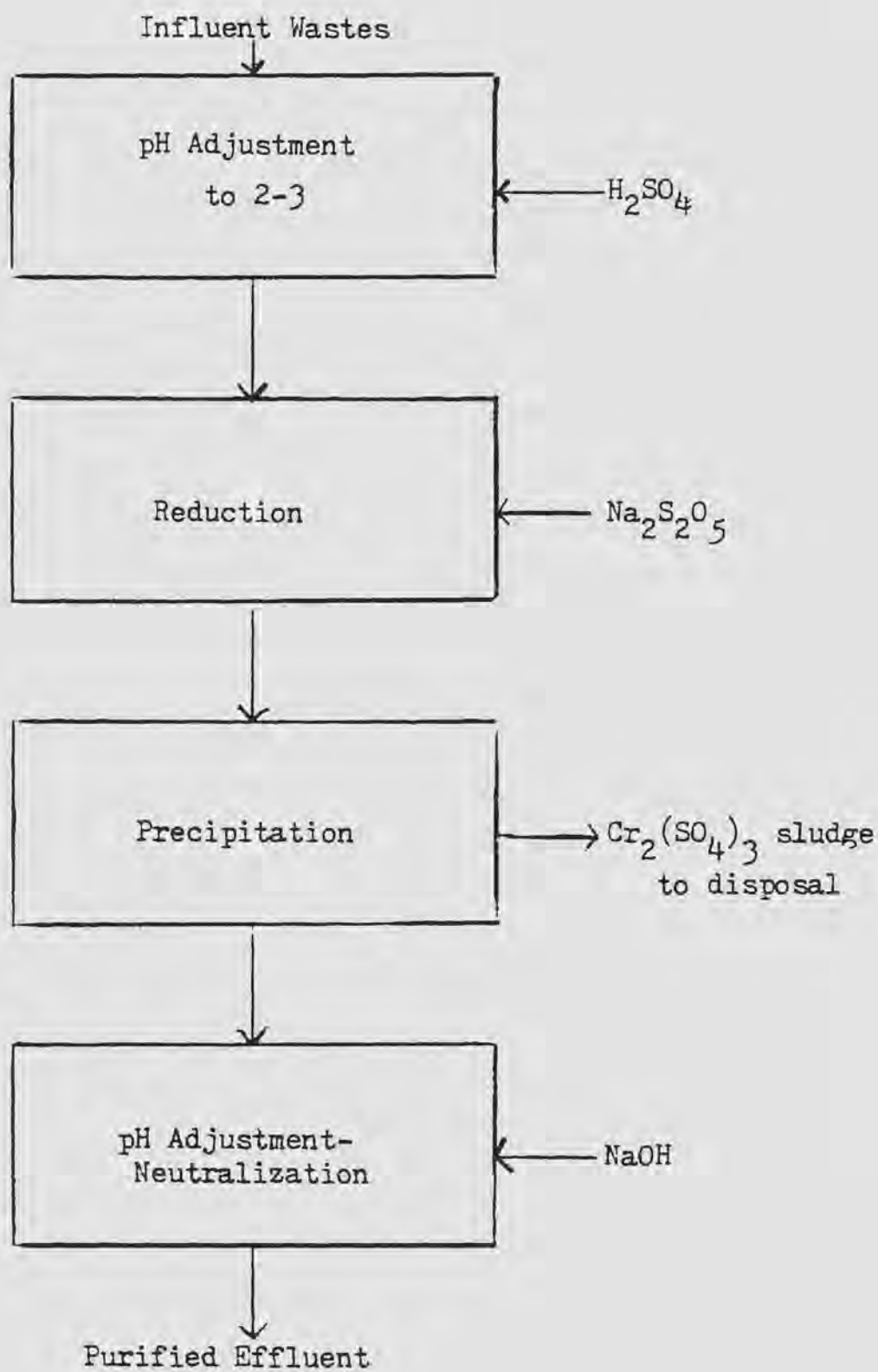
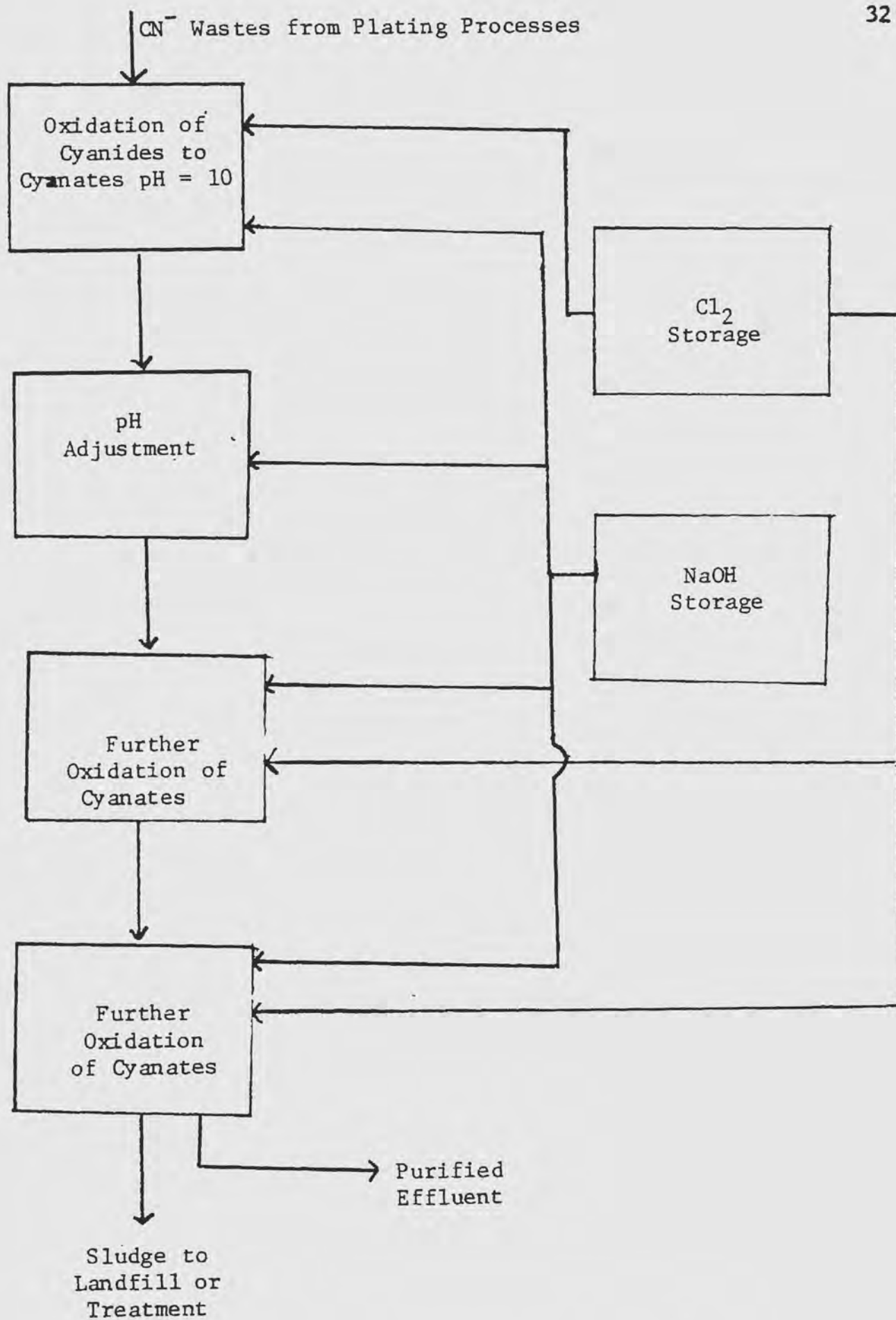


Fig. 3. Flow chart for chemical reduction of Cr^{+6}

Fig. 4. Chemical oxidation of CN^-

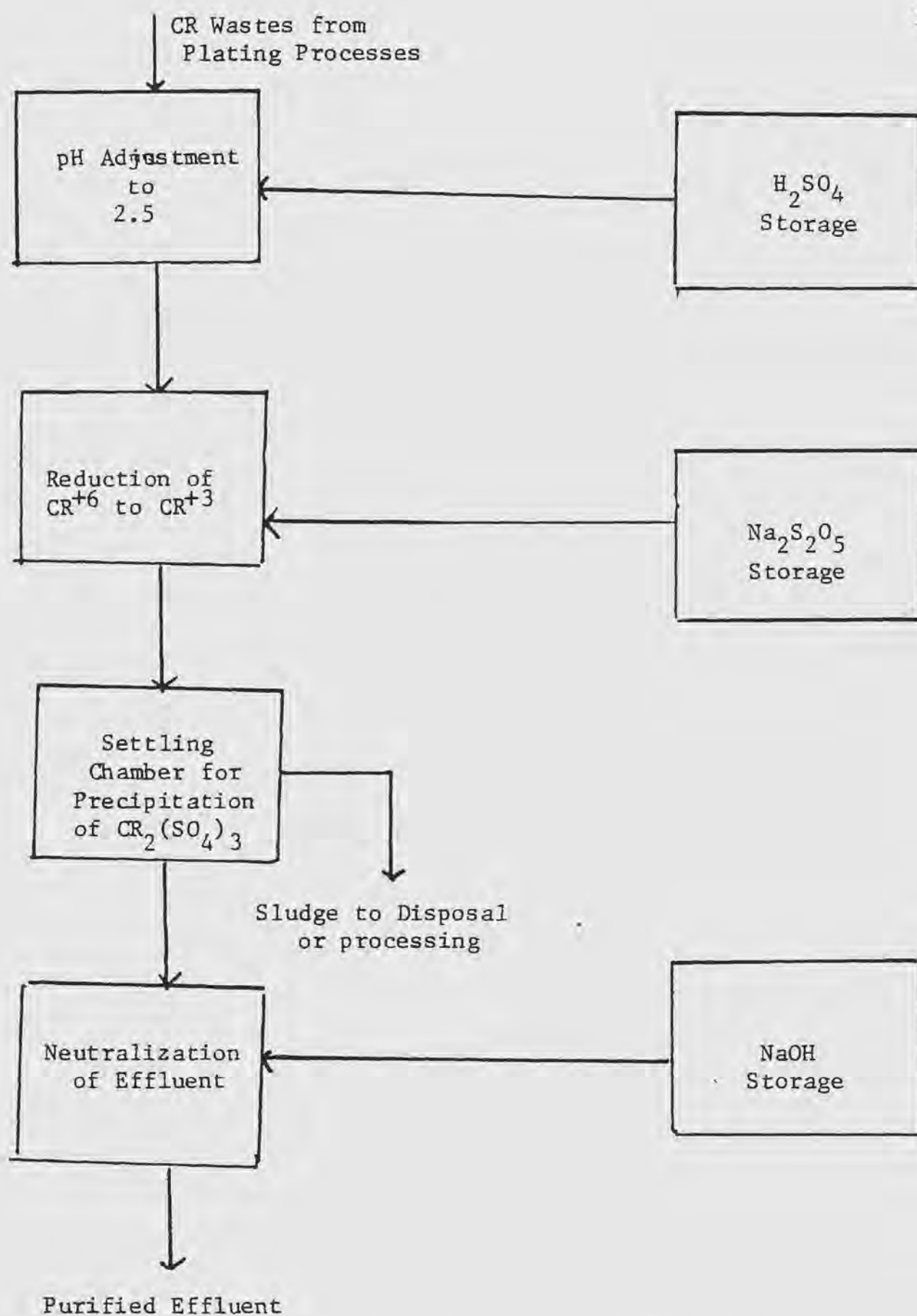


Fig. 5. Chemical reduction CR^{+6}

Carbon adsorption can be used for both chromium and cyanide containing waste streams. In order for adsorption of cyanides to occur, the cyanide must be in the form of a metal complex. Copper is the metal of choice, since it complexes with free CN^- quickly and is not affected by the presence of other metals. Copper is added as copper sulfate (see Figure 6). Because the natural pH of cyanide wastes is around 10, the solution is pH adjusted back to 6 or 7 using sulfuric acid. The carbon beds are regenerated periodically, producing a caustic solution which must be neutralized and a CuSO_4 solution which can be reused or sold (Battelle Laboratories 1971B).

The carbon adsorption system for chromium involves first lowering the pH of the solution to 2-3. After the waste stream has passed through the adsorption beds, it is neutralized using NaOH. The carbon beds are regenerated with NaOH, yielding Cr^{+6} in a concentrated solution from which chromium can be recovered and sold (Battelle Laboratories 1971A).

If careful pH monitoring is followed, carbon adsorption of both CN^- and Cr^{+6} can reach efficiencies of 99%. The system represents proven technology, but has only recently been applied to plating wastes.

Toxic substances can also be removed by electrolytic treatment of plating wastes. Cyanides are concentrated and oxidized at the anode sites in an electro-chemical cell. This step is 65% efficient in oxidizing CN^- . The remaining solution is drained into a

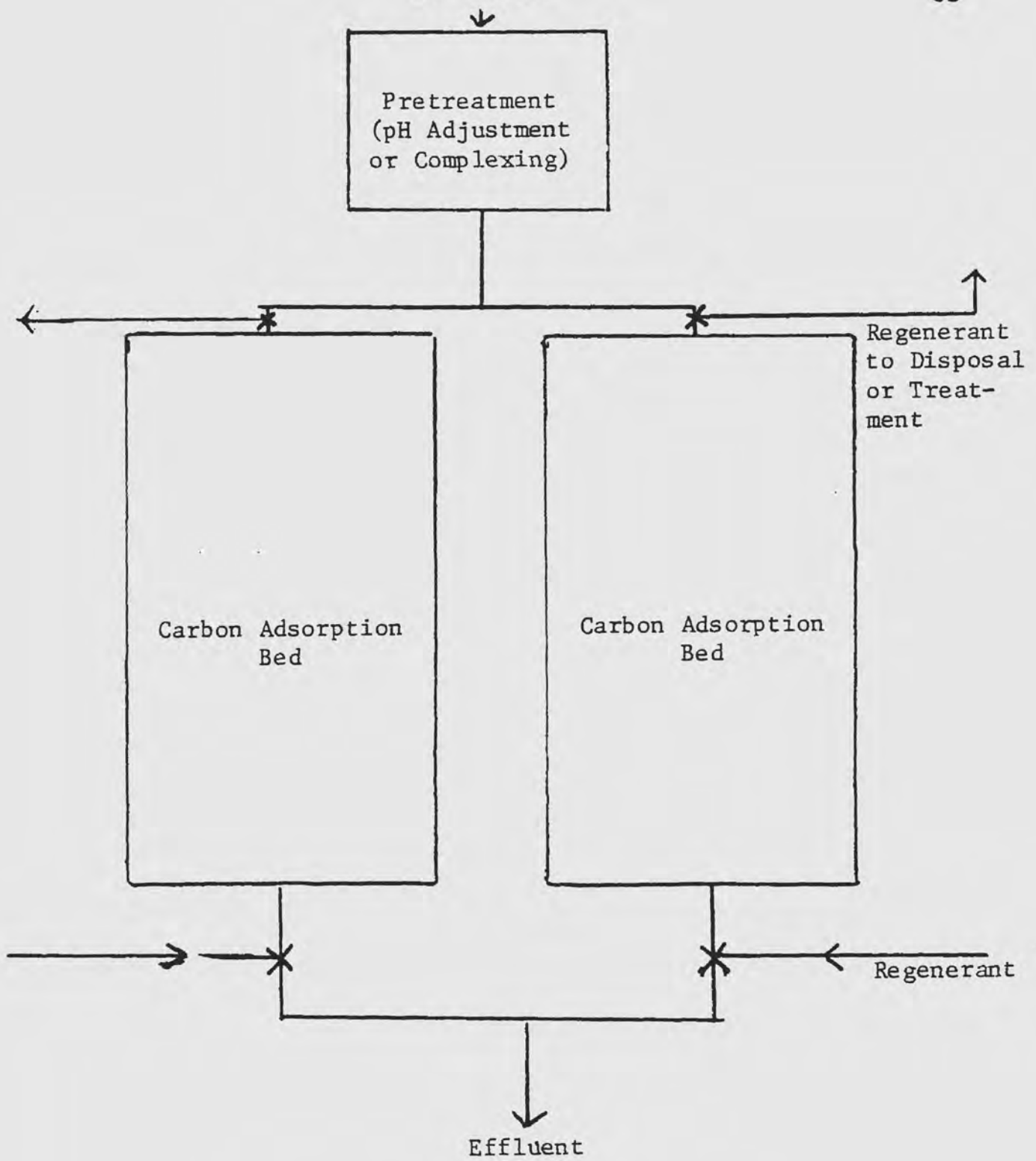


Fig. 6. Carbon adsorption

tank where hypochlorite is added to complete the destruction of CN^- (Warner 1975). A sludge containing various toxic metals is produced and this must be treated and/or disposed of properly.

The electrochemical treatment process for chromium wastes begins with adjusting pH to 1.5 to 2.0. The waste is run through an electrochemical cell where Cr^{+6} is reduced to Cr^{+3} at the cathode. The trivalent chromium which is still in solution at the low pH then goes to a holding tank, where NaOH is added to a pH of 8.2. The rise in pH causes the chromium to precipitate as insoluble trivalent chromium hydroxide. It is not presently economical to recover $\text{Cr}(\text{OH})_3$, so the sludge must be disposed of (Warner 1975).

Electrochemical treatment is most applicable to high concentration, high volume wastewater streams. It is capable of 99.4% efficiency in an 3500 mg/l concentration waste stream. No chemicals are used in either CN^- oxidation or Cr^{+6} reduction which eliminates both chemical storage and control (Costle 1978). Application of electrochemical treatment to plating wastes is still in the experimental stage.

Ion exchange and reverse osmosis are most useful when they are used with a closed-loop rinse electroplating process (See Fig. 7). In this process, elements which have been plated are rinsed in a series of decreasingly concentrated baths with the last rinse the purest. Water is routed from the last rinse to the first then processed using either reverse osmosis (RO) or ion exchange. The concentrated metal containing portion of the effluent is returned to the

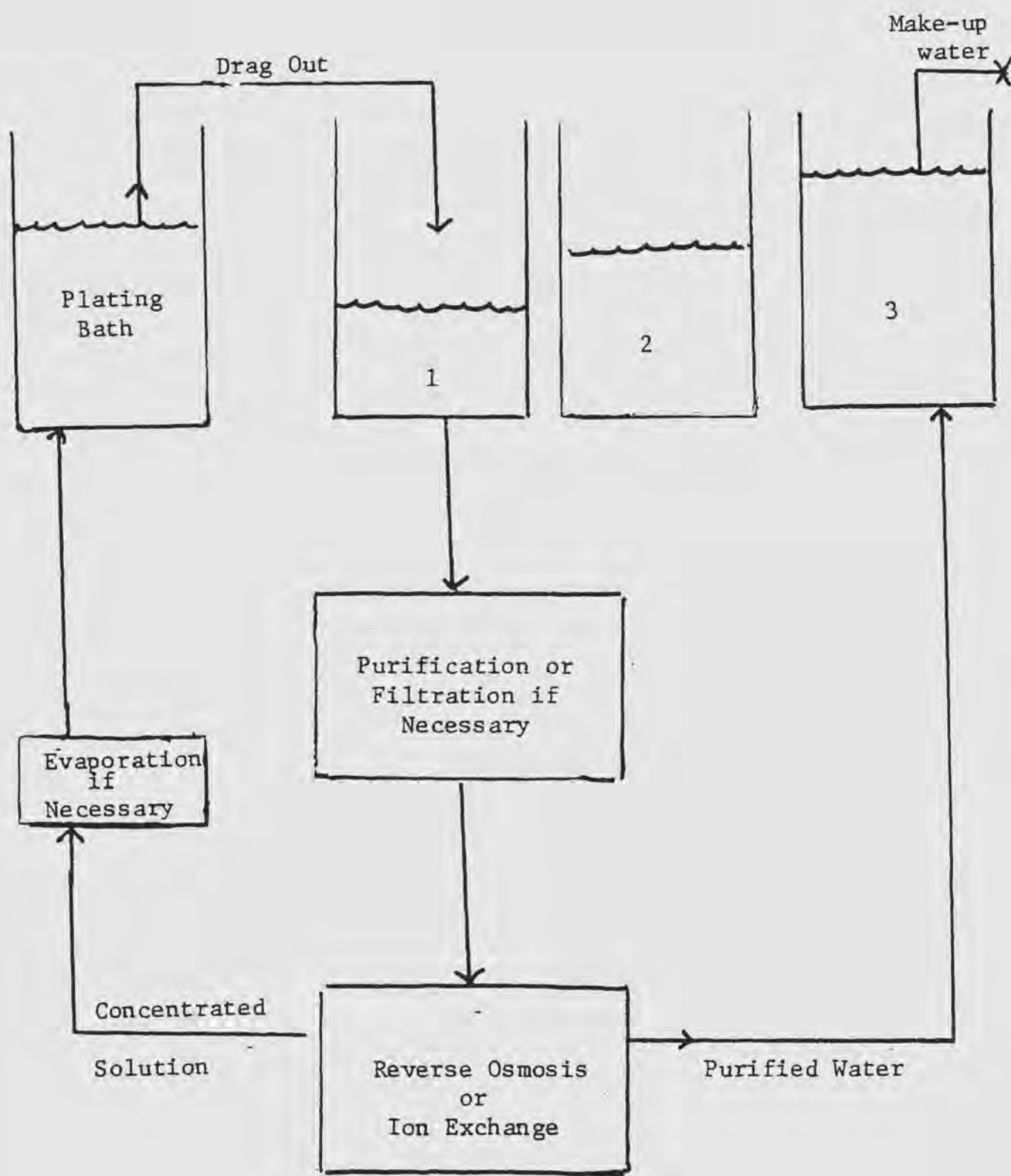


Fig. 7. Closed-loop rinse

plating baths and the purified water is returned to the rinsing baths. If closed-loop rinses were not used, both processes would have a concentrated liquid waste which would have to be disposed of or processed for metal recovery (Warner 1975).

Ion exchange is extremely efficient (99.5%) in removing Cr^{+6} . Almost all of the chromic acid that enters the rinse system is recovered using this system. For cyanides, however, efficiency of removal is only 75%. Ion exchange resins are easily clogged and become very inefficient in the presence of excessive suspended solids (Costle 1978).

Reverse osmosis is at present difficult to apply to both CN^- and Cr^{+6} wastes, since the membranes employed in the process have very short useful lives if exposed to extremes of pH. In addition RO membranes become plugged very easily. RO has potential applications to plating wastes, but this needs to be more thoroughly demonstrated (Donnelly 1976).

Hospital Wastes

Hospitals are among the greatest volume contributors of hazardous wastes in the ECFR. These hazardous wastes include biological wastes, such as human and animal remains, blood, bacteriological cultures and contaminated bandages; radiological wastes; and chemical wastes. For pathological biological wastes the only disposal alternative is incineration. Radiological wastes must be stored until they have decayed to a non-hazardous level of radioactivity (Kiefer 1974).

Although hospitals, in practice, attempt to segregate pathological wastes from uncontaminated trash, this segregation is not always successful. This may result in greater amount of contaminated material. Pathological content of hospital wastes ranges from 1% to 17% (Bell 1978).

For incineration of wastes, hospitals have three alternatives: (1) transportation of the wastes to another hospital or pathological incinerator for disposal, (2) incineration on site without heat recovery, (3) incineration on site with heat recovery. These three alternatives are closely related to the size of the hospital. Alternative one is most economical for very small hospitals, and alternative three would only be economical for large hospitals. These are discussed in more detail in Chapter 4.

Pesticide Wastes

Agriculture is an important industry in the ECFR, with three percent of the total land area in the five counties used for citrus crops alone. Very little is known about the actual amounts and kinds of pesticides that are used in the area. There is also very little information available on current disposal techniques.

There are no pesticide manufacturers in the ECFR, so any pesticide wastes are generated by distributors, commercial applicators or consumers. These are usually in the form of empty pesticide containers, dilute rinsing solutions or unwanted pesticides. Recommendations for disposal of pesticides were published by the EPA in the Federal Register in 1974. Disposal methods included

placement in a chemical landfill, incineration and recycling of metal containers (Day 1976). Soil injection was recommended if specific guidance was obtained from appropriate authorities. Open dumping is specifically prohibited, and open burning and ocean dumping were not recommended. Photodecomposition in lagoons and chemical degradation are also not advised, since total decomposition can't be assured.

An EPA survey shows that, in practice, much open dumping and burning occur and many pesticide containers are placed in sanitary landfills. Chemical distributors in the area dispose of waste pesticides by soil percolation and landfill (Little 1977).

IV ECONOMIC CONSIDERATIONS IN WASTE T/D

Economics of the three wastes studied in the previous chapter--pesticides, hospital wastes, and plating wastes--economic data were obtained for comparison of different alternatives for T/D. The economic data were assembled as follows.

Cost data were first corrected to 1978 dollars using the Chemical Engineering Economic Indices ("Economic Indices" 1963). To obtain capital investments for different flow rates, costs were scaled using the formula:

$$\text{Cost a} \times \frac{\text{capacity b}}{\text{capacity a}}^{.6} = \text{cost b}$$

Where a is the original plant and b is the size plant to which scaling is desired (Peters and Timmerhaus 1968). Man hours were scaled using a similar formula with a coefficient of 0.2. Amortization was computed 8% of the capital per year, and maintenance at 1% of the capital per year. Labor was computed at \$10 per hour, which included overhead. Power was computed at \$0.04/kwh and fuel at \$2.00/10⁶ BTUs. It should be noted that the costs obtained are the result of a Phase I study. They are presented for illustrative purposes only, and should not be used for design.

Plating Wastes

Eight methods of plating wastes treatment were considered (Table 3). Capital and operating and maintenance costs for processes

FIGURE 8

- 1) reverse osmosis
- 2) ion exchange
- 3) electrochemical oxidation
- 4) chemical oxidation
- 5) carbon adsorption - 16 hour day
- 6) carbon adsorption - 8 hour day
- 7) oxidation
- 8) carbon adsorption
- 9) electrochemical oxidation
- 10) reverse osmosis
- 11) ion exchange

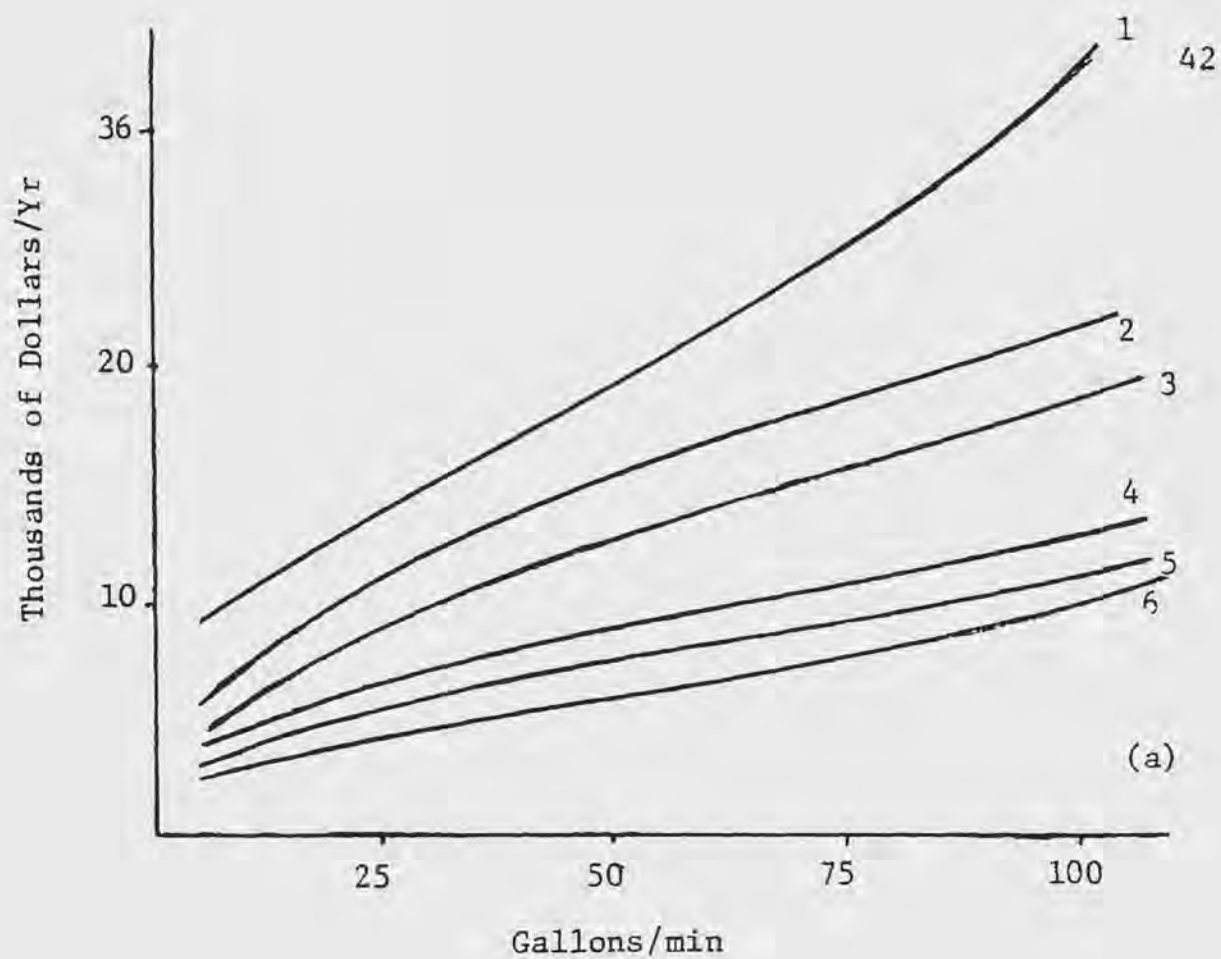


Fig. 8. CN^- removal costs:
 a) operating and maintenance
 b) capital

TABLE 3
PLATING WASTE DISPOSAL COSTS

PROCESS AND REFERENCE	CAPITAL INVESTMENT IN DOLLARS			OPERATING AND MAINTENANCE COSTS - DOLLARS/YR		
	5 GPM	20 GPM	100 GPM	5 GPM	20 GPM	100 GPM
Carbon Adsorption of CN^- .00188 lb CN^-/gal I 8 hour day II 16 hour day (Battelle Lab. 1971B p80)	20,558	47,230	124,050	I 1927 II 2640	4124 5118	9791 11,361
Oxidation of CN^- .00085 lb CN^-/gal (Costle, 1978, p 321)	21,594	49,610	130,302	3087	6175	13,807
Electrochemical and Chemical Oxidation of CN^- .00085 lb CN^-/gal (Warner, 1975, p 132)	24,110	46,753	122,798	4131	8263	18,477
Carbon Adsorption of Cr^{+6} .00083 lb Cr/gal (Battelle Lab. 1971A, p 80)	5,679	12,932	33,967	1796	2776	5123
Carbon Reduction of Cr^{+6} I .00014 lb Cr/gal II .0013 lb Cr/gal (Warner, 1975, p 123)	7,869	19,376	55,156	I 3689 II 6580	5458 9301	10,038 15,503
Electrochemical Reduction of Cr^{+6} I .00014 lb Cr/gal II .0013 lb Cr/gal (Warner, 1975, p 123)	24,916	57,244	150,353	I 4442 II 5204	7582 8599	15,960 17,421
Reverse Osmosis (Costle, 1978, p 336)	9,583	22,017	57,828	8775	12,605	35,700
Ion Exchange (Costle, 1978, p 335)	7,162	16,372	43,000	5767	10,762	22,203

FIGURE 9

- 1) reverse osmosis
- 2) ion exchange
- 3) electrochemical reduction, .0013 lb/gal
- 4) chemical reduction, .0013 lb/gal
- 5) electrochemical reduction, .00014 lb/gal
- 6) chemical reduction, .00014 lb/gal
- 7) carbon adsorption
- 8) electrochemical reduction
- 9) reverse osmosis
- 10) chemical reduction
- 11) ion exchange
- 12) carbon adsorption

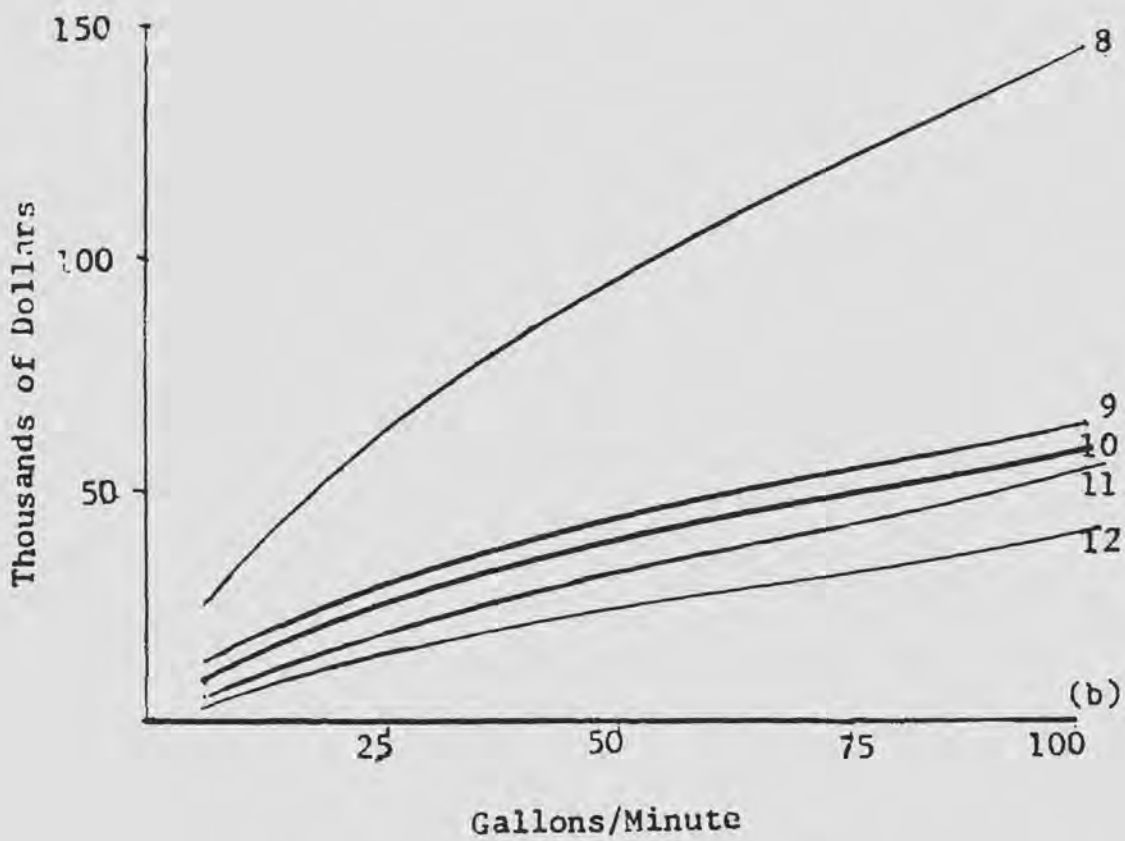
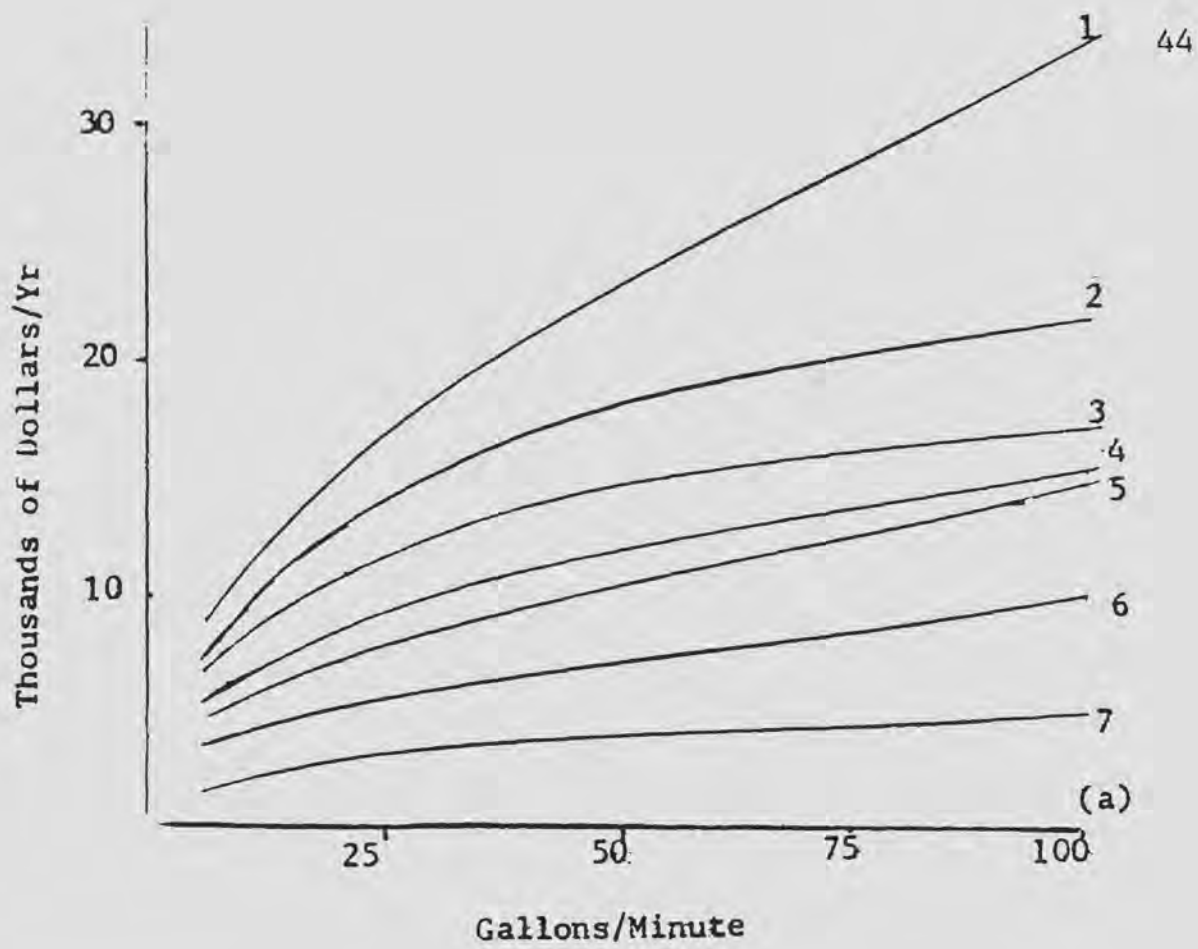


Fig. 9. CR⁶ removal costs:
a) operating and maintenance
b) capital

FIGURE 10

- 1) electrochemical oxidation
- 2) chemical oxidation
- 3) carbon adsorption

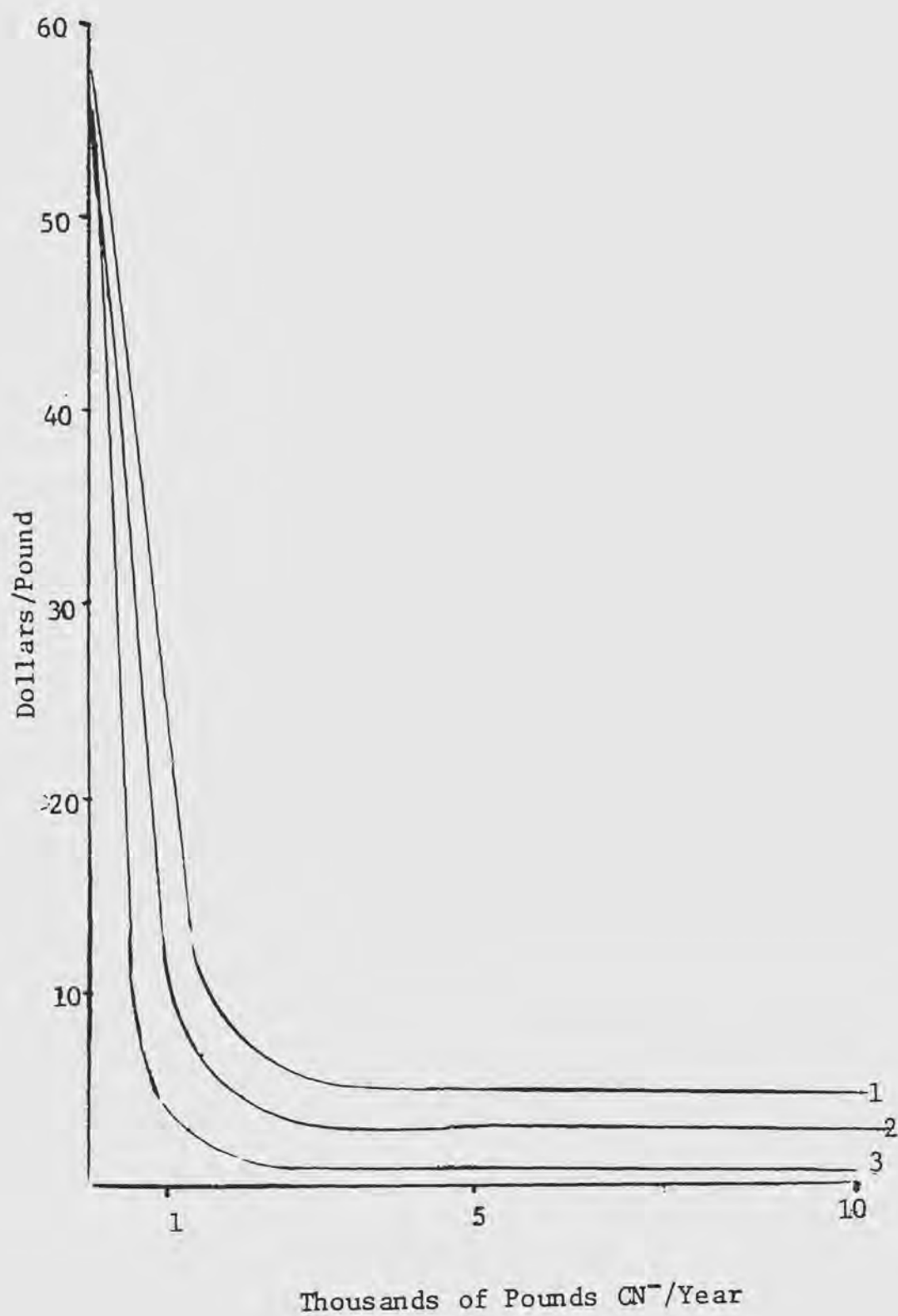


Fig. 10. CN^- disposal costs in dollars/lb

FIGURE 11

- 1) electrochemical reduction
- 2) chemical reduction
- 3) carbon adsorption

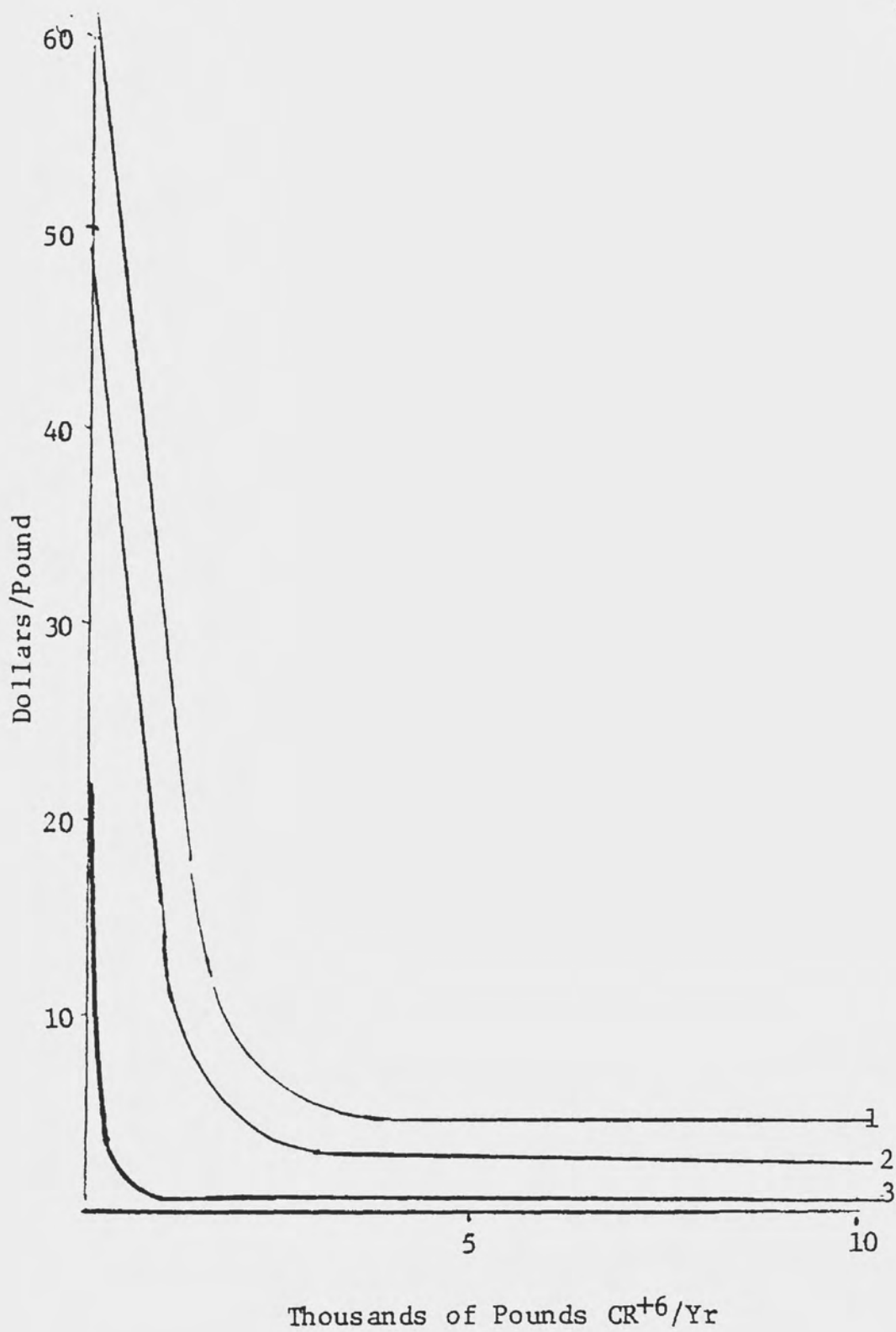


Fig. 11. CR^{+6} disposal costs in dollars/pound

FIGURE 12

- 1) reverse osmosis
- 2) electrochemical reduction, .0013 lb/gal
- 3) electrochemical reduction, .00014 lb/gal
- 4) ion exchange
- 5) chemical reduction, .0013 lb/gal
- 6) chemical reduction, .00014 lb/gal
- 7) carbon adsorption
- 8) reverse osmosis
- 9) ion exchange
- 10) electrochemical oxidation
- 11) chemical oxidation
- 12) chemical oxidation
- 13) carbon adsorption - 16 hour day
- 14) carbon adsorption - 8 hour day

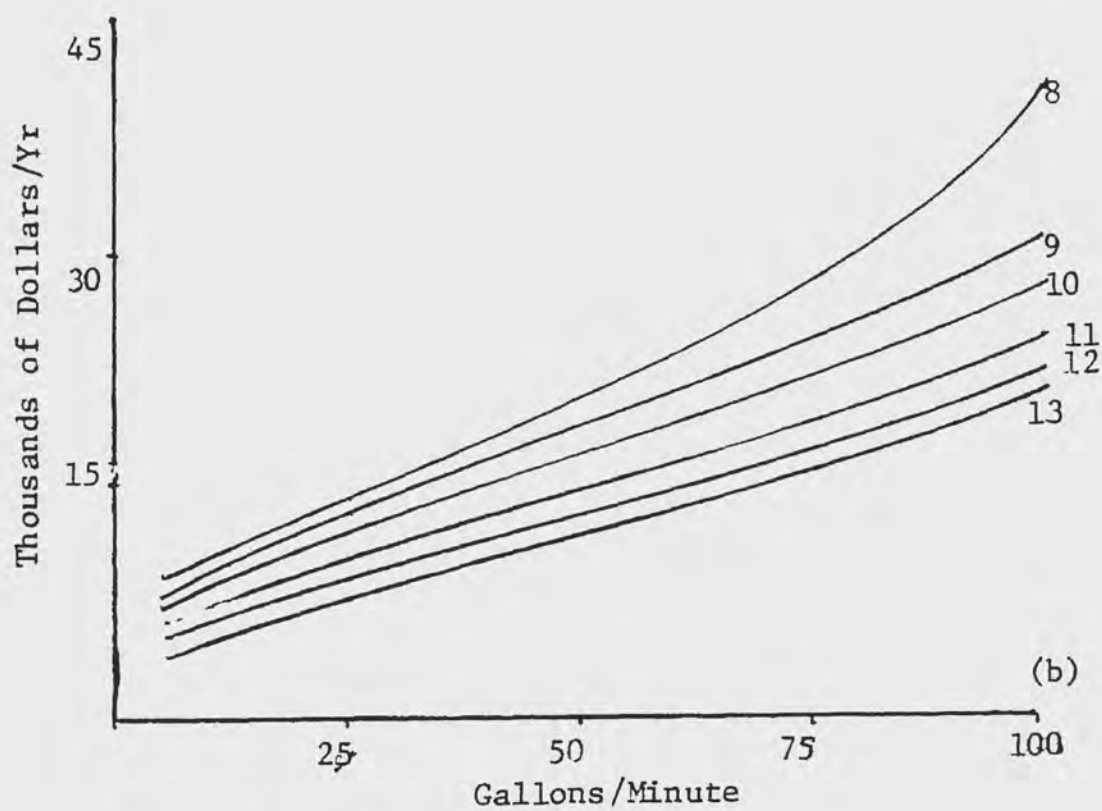
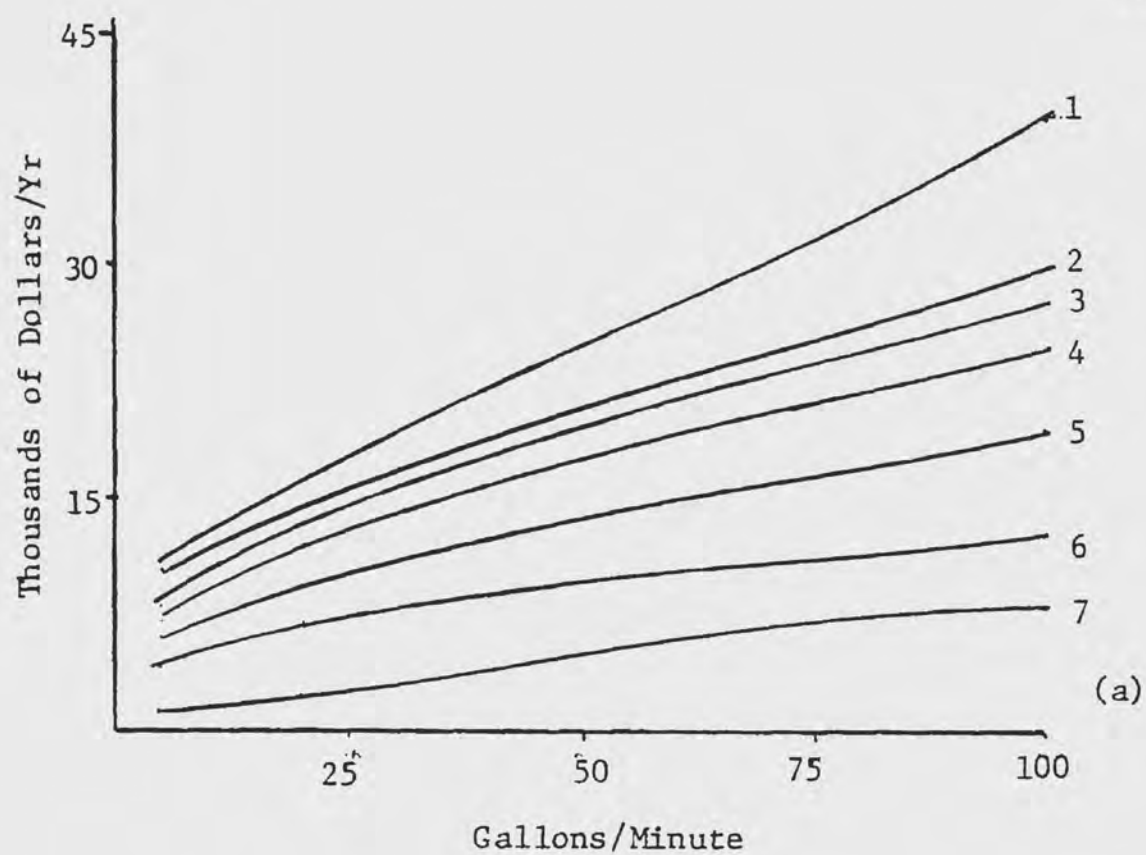


Fig. 12. Total annual costs for removal
a) CR^{+6}
b) CN^{-}

TABLE 4

HOSPITAL INCINERATOR COSTS

FEED RATE	# POUNDS/ DAY	TOTAL CAPITAL INVESTMENT INSTALLED	HEAT RECOVERY EQUIPMENT ALONE	# MAN HOURS/WK	O&M TOTAL	CREDITS FOR STEAM	REFERENCES
1200 lb/hr	9,000	\$108,031	\$49,500	52	\$38,971	\$10,510	Myes, 1978 Lucas, 1978
900 lb/hr	8,000	90,904	48,000	52	37,292	9,335	Myes, 1978 Wygant, 1978
350 lb/hr	2,800	39,705	-0-	52	32,546	-0-	Meurer, 1978 Myes, 1978
85 lb/hr (base)	765	\$ 6,600	-0-	40	\$22,500	-0-	Myes, 1978

FIGURE 13

- 1) without heat recovery credits
- 2) with heat recovery credits

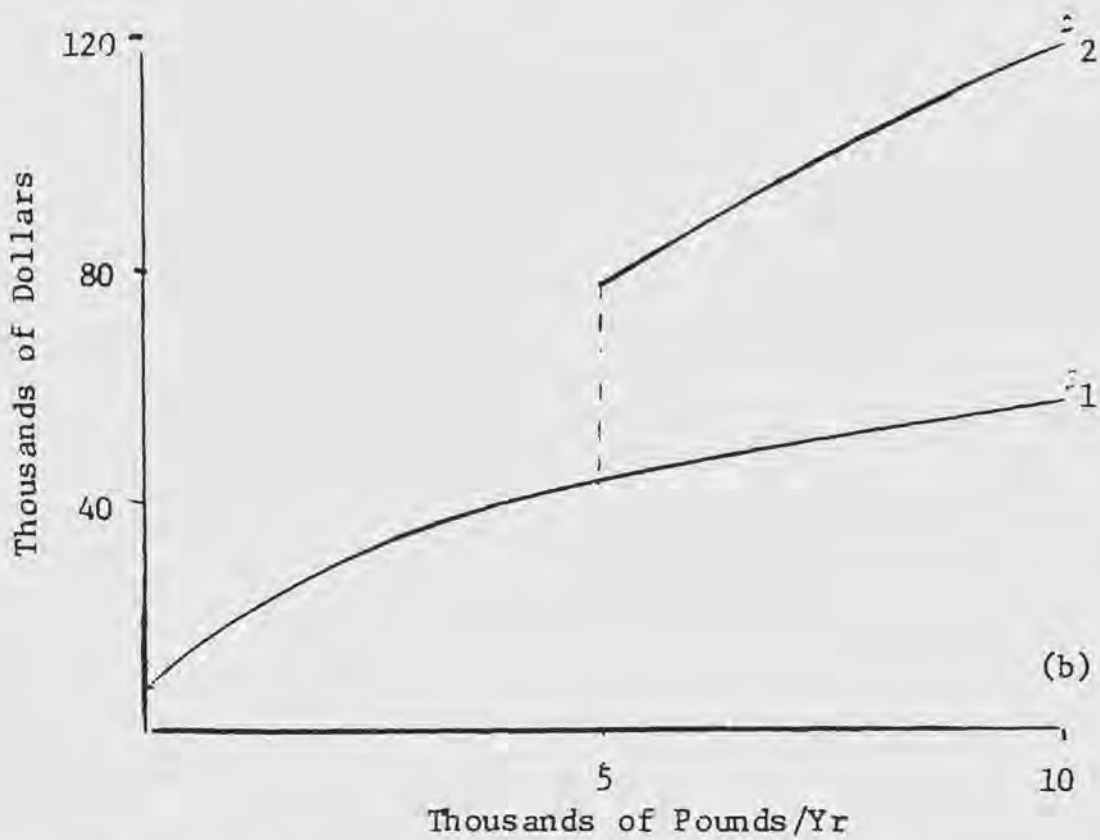
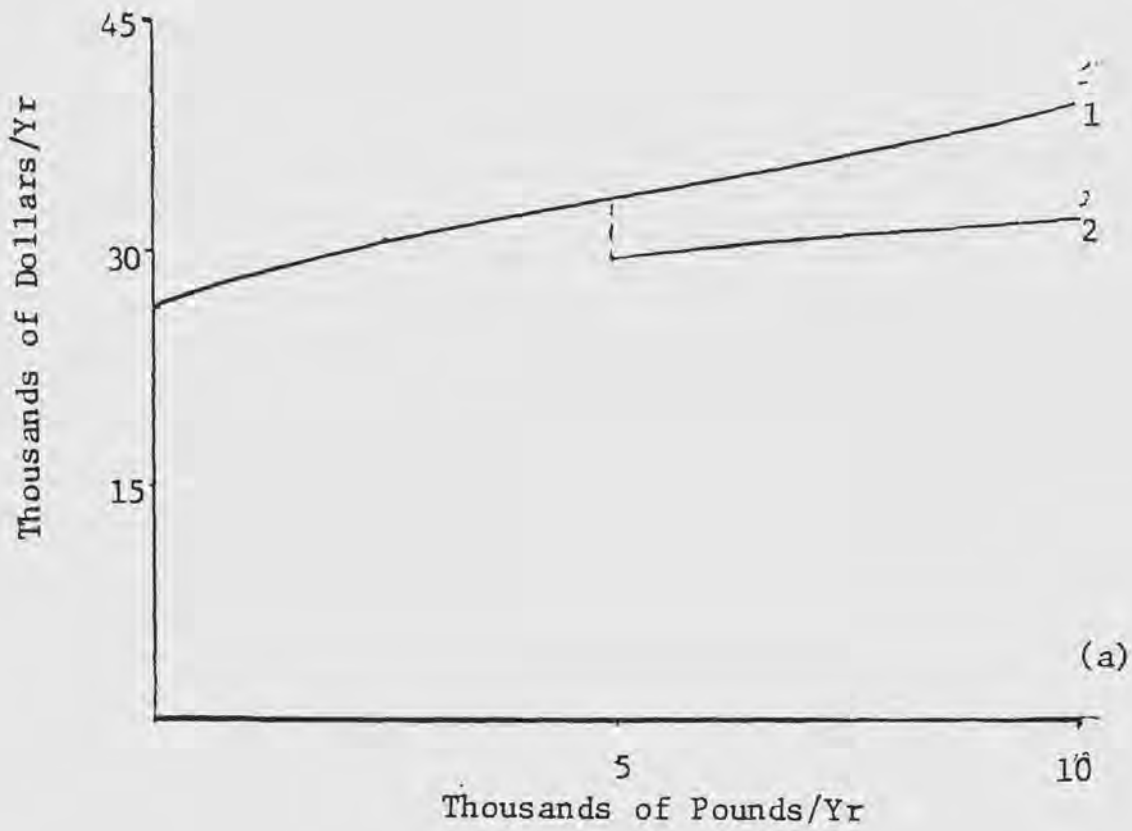


Fig. 13. Hospital - capital and operating costs for incinerators (a) operation & maintenance (b) capital

removing cyanide and chromium respectively were computed, and are shown in Figures 8 and 9. Since the processes studied did not start at the same influent concentration of contaminants, the cost of removing cyanide or chromium per pound was calculated, and this is shown in Figures 10 and 11. Concentrations were not stated for reverse osmosis and ion exchange. Both of these processes, however, function most effectively at low concentrations since high concentrations cause plugging of the membranes. The total cost of each process including depreciation (by the straight line method, assuming twelve years useful life) is shown in Figure 12.

Hospital Wastes

Costs for incinerators for hazardous wastes were determined for hospitals on the basis of the number of pounds of wastes generated per day (See Table 4). The base capital cost (minimum size pathological incinerator) was \$6,600, and the base operating cost (for burning ten pounds per day) was determined to be \$22,500 (Myes 1978). The cost of heat recovery equipment and the credits from heat recovery are shown in Figure 13. The minimum pounds per day waste generation at which a heat recovery system would be profitable was calculated to be 5000 lb/day, using the present worth criterion and 12% as the minimum rate of return.

Economics of Pesticide Disposal

For disposal of dilute or concentrated pesticides or empty pesticide containers, the following alternatives exist in practice:

1. open dumping
2. open burning
3. sanitary or chemical landfill
4. incineration of concentrated pesticides
5. recycling/reuse of containers
6. soil injection
7. use as a diluent for making up new pesticide solutions
8. send back to manufacturer
9. burial

Open dumping, open burning, and burial are least expensive.

The only cost would be for manpower to attend the fire in burning, or to bury the pesticides. However, as discussed above, these methods are not recommended due to possible environmental damage.

Sanitary landfill is acceptable as a disposal method for containers providing that geological conditions are such that leaching of the pesticides to the water table is precluded. For concentrated unwanted pesticides, only a chemical landfill is acceptable (Little 1977). A local sanitary landfill charges \$10/ton for chemical wastes (Davis 1978). A chemical landfill is not available in Florida, so wastes to be disposed of in this way would have to be transported over a substantial distance. Chemical landfill costs are typically \$40-60/ton in addition to transportation (Day 1976). By contrast, to build a chemical landfill in the ECFR which could accept 6,000 yd³ of waste per year would cost approximately \$487,000. This includes \$4,000/acre for a rolled clay liner to prevent leaching. Other

liners range from \$10,000/acre (for asphalt) to \$35,000/acre (for hypalon). Operating expenses would be an additional \$200,000/yr (Fields and Lindsey 1975). Obviously, this expense is not justified in this area at the present time.

Incineration, in order to fully destroy pesticides, must take place at 1000°C with at least 2 seconds dwell time. This is the most expensive of the recommended pesticide disposal methods (\$90-115/ton) (Day 1976). The cost of a 2.5×10^6 lb/yr pesticide incinerator would be approximately \$660,000. Operating costs would be an additional \$110,000/year. Given the relatively small amount of unwanted pesticides generated in the ECFR, this expense also seems unwarranted (Little 1977).

Metal pesticide drums can be recycled by a cooperage firm. These might be purchased from the user at \$.30-.75/drum and resold at \$11.00/drum (Little 1977).

Dilute solutions may be injected into soil with a plow. This method of disposal is most effective when used with a known non-persistent pesticide at a rate of no more than 500 lb/acre. Eighteen months should be allowed to pass before more pesticide is applied. This is a very inexpensive process--no special equipment or transportation costs are involved. The process is not recommended for concentrated pesticides (Day 1976).

Dilute pesticide solutions that have been produced by rinsing pesticide containers could be used to make up new solutions of pesticides for application. This could save up to enough pesticide to

treat $\frac{1}{2}$ acre. Use of rinsewater as a diluent is highly recommended by the EPA (Day 1976). Figure 18 presents costs for pesticide waste disposal as a function of number of tons to be disposed.

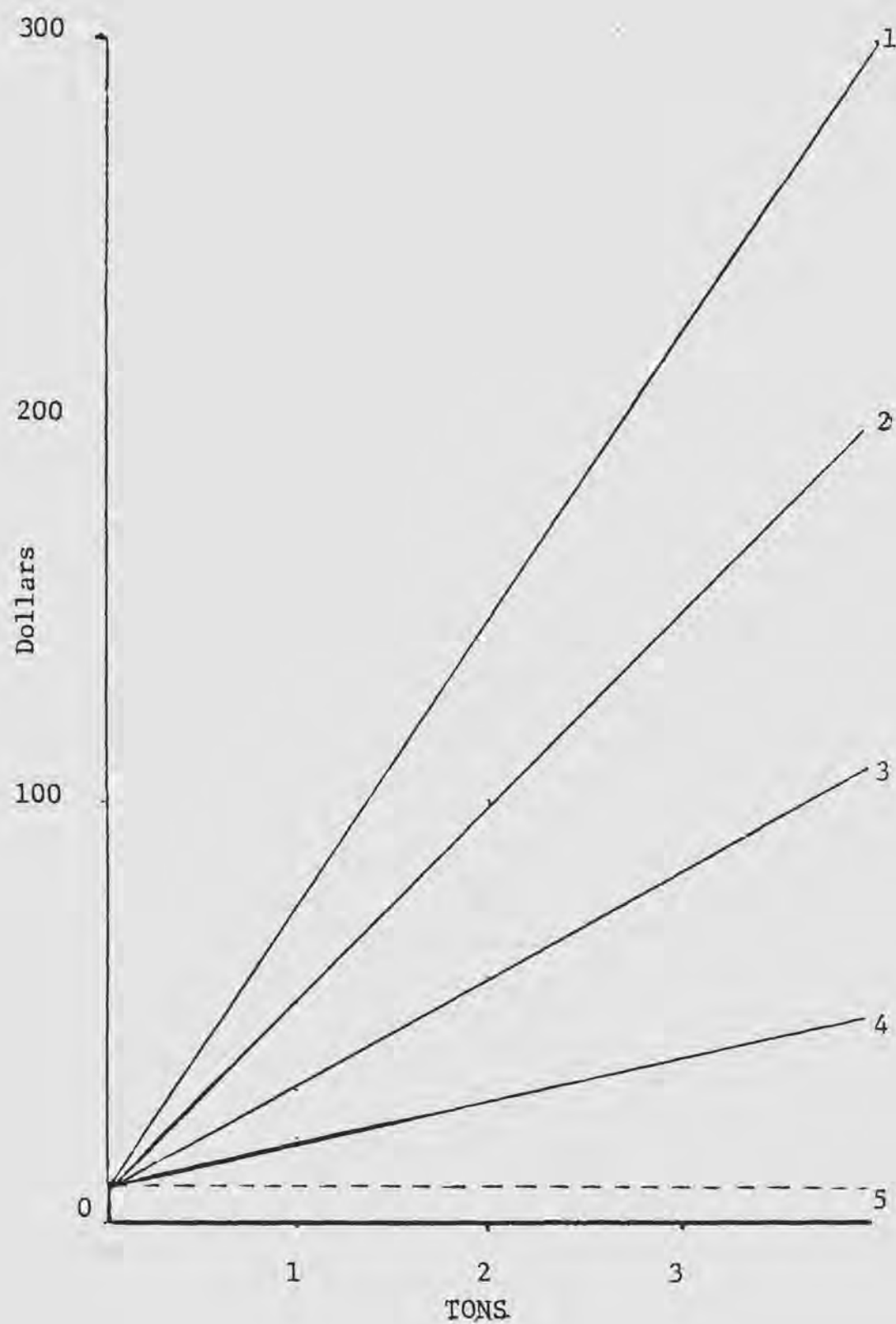


Fig. 14. Pesticide disposal costs

1) incineration (2) chemical landfill (3) toxic waste-sanitary landfill (4) normal waste-sanitary landfill (5) open dumping

V CONCLUSIONS AND RECOMMENDATIONS

There are few large industries in the ECFR presently producing hazardous wastes. There are, however, a large number of small sources of hazardous wastes, and these, since they produce small quantities of toxic materials, are likely to be less well regulated and less organized in their disposal methods than large industries. Such small sources include small plating shops, hospitals and pesticide distributors, applicators, and consumers. Because of the dependence of the ECFR on its groundwater resources, these small waste producers are of concern.

There are no chemical landfills or commercial hazardous waste disposal firms in the area, so that wastes generated by industries without in-plant disposal facilities will have to be transported out of the region to the manufacturer or to a hazardous waste facility.

Several alternatives for T/D of wastes found in the ECFR were presented. These included chemical, physical, and biological treatment, incineration, and ultimate disposal. In plating and hospital waste treatment, opportunities for energy and material recovery were noted. The waste composition and required final product determine the process used for T/D. The desired rate of return on an energy/material recovery system and the volume of wastes to be processed determined whether or not energy or material will be recovered. For a source producing a very small amount of waste (i.e. consumer pesti-

cide wastes) or for emergency spills of hazardous materials, choice of T/D method may also be determined by what methods are immediately available.

There is little detailed information about the amounts, types, and disposal methods of hazardous wastes in the ECFR. It is recommended that the quantities and sources of hazardous wastes in the region be studied in more detail. This is especially needed for pesticides, since there appears to be almost no data available concerning their use and disposal.

Since the ECFR is dependent on its groundwater, investigation of the effects of land disposal of hazardous wastes in the area seems important. Little information is available on the ECFR soils and their uptake of hazardous materials or on the movement of wastes through the soils.

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